

# Soft X-ray characterisation of the long term properties of Supergiant Fast X-ray Transients<sup>★</sup>

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## ABSTRACT

**Context.** Supergiant Fast X-ray Transients (SFXTs) are High Mass X-ray Binaries (HMXBs) characterised by a hard X-ray ( $\geq 15$  keV) flaring behaviour. These flares reach peak luminosities of  $10^{36}$ – $10^{37}$  erg s<sup>-1</sup> and last a few hours in the hard X-rays.

**Aims.** We investigate the long term properties of SFXTs by examining the soft (0.3–10 keV) X-ray emission of the three least active SFXTs in the hard X-ray and by comparing them with the remainder of the SFXT sample.

**Methods.** We perform the first high-sensitivity soft X-ray long-term monitoring with *Swift*/XRT of three relatively unexplored SFXTs, IGR J08408–4503, IGR J16328–4726, and IGR J16465–4507, whose hard X-ray duty cycles are the lowest measured among the SFXT sample. We assess how long each source spends in each flux state and compare their properties with those of the prototypical SFXTs.

**Results.** The behaviour of IGR J08408–4503 and IGR J16328–4726 resembles that of other SFXTs, and it is characterized by a relatively high inactivity duty cycle (IDC) and pronounced dynamic range (DR) in the X-ray luminosity. We found DR~7400, IDC~67 % for IGR J08408–4503, and DR~750, IDC~61 % for IGR J16328–4726 (in all cases the IDC is referred to the limiting flux sensitivity of XRT, i.e.  $1\text{--}3 \times 10^{-12}$  erg cm<sup>-2</sup> s<sup>-1</sup>). In common with all the most extreme SFXT prototypes (IGR J17544–2619, XTE J1739–302, and IGR J16479–4514), IGR J08408–4503 shows two distinct populations of flares. The first one is associated with the brightest outbursts (X-ray luminosity  $L_X \geq 10^{35-36}$  erg s<sup>-1</sup>), while the second comprises less bright events with typical luminosities  $L_X \leq 10^{35}$  erg s<sup>-1</sup>. This double-peaked distribution of the flares as a function of the X-ray luminosity seems to be a ubiquitous feature of the extreme SFXTs. The lower DR of IGR J16328–4726 suggests that this is an intermediate SFXT. IGR J16465–4507 is characterized by a low IDC~5 % and a relatively small DR~40, reminiscent of classical supergiant HMXBs. The duty cycles measured with XRT are found to be comparable with those reported previously by BAT and *INTEGRAL*, when the higher limiting sensitivities of these instruments are taken into account and sufficiently long observational campaigns are available. By making use of these new results and those we reported previously, we prove that no clear correlation exists between the duty cycles of the SFXTs and their orbital periods.

**Conclusions.** The unique sensitivity and scheduling flexibility of *Swift*/XRT allowed us to carry out an efficient long-term monitoring of the SFXTs, following their activity across more than 4 orders of magnitude in X-ray luminosity. While it is not possible to exclude that particular distributions of the clump and wind parameters may produce double-peaked differential distributions in the X-ray luminosities of the SFXTs, the lack of a clear correlation between the duty cycles and orbital periods of these sources make it difficult to interpret their peculiar variability by only using arguments related to the properties of supergiant star winds. Our findings favour the idea that a correct interpretation of the SFXT phenomenology requires a mechanism to strongly reduce the mass accretion rate onto the compact object during most of its orbit around the companion, as proposed in a number of theoretical works.

**Key words.** X-rays: binaries – X-rays: individual: IGR J08408–4503 – X-rays: individual: IGR J16328–4726 – X-rays: individual: IGR J16465–4507.

## 1. Introduction

Supergiant fast X-ray transients (SFXTs) are the most recently recognized (e.g. Sguera et al. 2005) class of High Mass X-ray Binaries (HMXBs). They are associated with OB supergiant stars via IR/optical spectroscopy, and display hard X-ray ( $\geq 15$  keV) outbursts significantly shorter than those of typical Be/X-ray binaries, characterised by bright flares (peak luminosities of  $10^{36}$ – $10^{37}$  erg s<sup>-1</sup>) lasting a few hours (Sguera et al.

2005; Negueruela et al. 2006a). These bright flares are often clustered together in longer outbursts, lasting from a few hours to a few days (e.g., Romano et al. 2007; Rampy et al. 2009; Romano et al. 2014). Their outburst spectra in the hard X-rays resemble those of HMXBs hosting accreting neutron stars, with spectrally hard power laws combined with high energy cut-offs, therefore it is generally assumed that all SFXTs might host a neutron star, even if pulse periods have only been measured for a few SFXTs. Since their quiescent luminosity is of the order of  $\sim 10^{32}$  erg s<sup>-1</sup> (e.g. in't Zand 2005; Bozzo et al. 2010), SFXTs display a quite characteristic dynamic range of 3–5 orders of magnitude. At the time of writing, the SFXT class consists of

<sup>★</sup> Tables 1–4 are available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via <http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/XXX/XXX>

**Table 5.** Summary of the *Swift*/XRT campaign on the three SFXTs in the new monitoring sample.

Name	Nickname	Campaign Start (yyyy-mm-dd)	Campaign End (yyyy-mm-dd)	N <sup>a</sup>	XRT Net Exposure (ks)	Outburst Dates (yyyy-mm-dd)	BAT Trigger Number
IGR J08408–4503	J08408	2011-10-20	2012-08-05	82	74.4	–	–
IGR J16328–4726	J16328	2011-10-20	2012-10-22	82	73.5	2011-12-29	510701
		2013-09-02	2013-10-24	16	14.5	–	–
IGR J16465–4507	J16465	2013-01-20	2013-09-01	65	58.6	–	–
Total				245	221.0		

**Notes.** <sup>(a)</sup> Number of observations obtained during the monitoring campaign.

14 sources (e.g. Romano et al. 2014, and references therein) and about as many candidates, that is, sources which have shown an SFXT-like flaring behaviour, but are still lacking a detailed classification of the optical companion. About 250 HMXBs are currently known to reside in our Galaxy and the Magellanic Clouds (Liu et al. 2005, 2006; Krivonos et al. 2012), so the SFXT population is quickly becoming not only a peculiar, but also a relevant portion of the HMXB population.

The detailed mechanisms responsible for the bright outbursts are still being debated. It is generally believed that they are related to either the properties of the wind from the supergiant companion (in’t Zand 2005; Walter & Zurita Heras 2007; Negueruela et al. 2008; Sidoli et al. 2007) and/or the presence of mechanisms regulating or inhibiting accretion (Grebenev & Sunyaev 2007, propeller effect; Bozzo et al. 2008a, magnetic gating). Recently, a model of quasi-spherical accretion onto neutron stars involving hot shells of accreted material above the magnetosphere (Elsner & Lamb 1977; Shakura et al. 2012, 2013) has also been proposed.

The long-term behaviour of SFXTs – away from the prominent bright outbursts – is naturally best observed by monitoring instruments, such as the Imager on Board the INTEGRAL Satellite (IBIS, Ubertini et al. 2003) or the Burst Alert Telescope (BAT, Barthelmy et al. 2005) on board *Swift* (Gehrels et al. 2004) that have now gathered data spanning about a decade each. Due to their sensitivity limits, however, these monitors mostly catch only the very bright flares. The low fluxes characteristic of the states outside the bright outbursts could only be studied extensively when a highly sensitive, soft X-ray (0.2–10 keV) telescope, the X-ray Telescope (XRT, Burrows et al. 2005) on board *Swift* was used in a two-year long series of pointed observations, 3–4 days apart, during a systematic study (Sidoli et al. 2008) of IGR J16479–4514, XTE J1739–302, IGR J17544–2619, and AX J1841.0–0536 (hereon J16479, J1739, J17544, and J1841, respectively). This first assessment of how long each source spends in each flux state yielded unexpected results. Not only the time spent in outburst was a small fraction (3–5 %) of the total (Romano et al. 2009), but also the four sources (which we shall call *initial monitoring sample* hereon) were found to spend most of their time at mean fluxes two orders of magnitude below the bright flares, at luminosities in the  $10^{33}$ – $10^{34}$  erg s<sup>−1</sup> range. The sources were detected in the soft X-ray for the majority of pointings so that their duty cycle of *inactivity* (Romano et al. 2011, and references therein) was relatively small (19–55 %), clearly at odds with what is generally observed in the hard X-rays. These datasets also established the ubiquitous flaring activity at all intensities and all timescales probed that were consistently observed with the XRT

as well as during deep pointed observations with *Suzaku* (e.g. Rampy et al. 2009) and *XMM-Newton* (e.g. Bozzo et al. 2010).

Further monitoring campaigns providing high-cadence, pointed observations for one or more orbital periods were performed on IGR J18483–0311, IGR J16418–4532, and IGR J17354–3255 (hereon J18483, J16418, and J17354, respectively) to primarily study the effects of orbital parameters on the observed flare distributions (Romano et al. 2010, 2012b; Ducci et al. 2013). We call this latter group *orbital monitoring sample*.

In this paper we continue our in depth exploration of the long term properties of SFXTs<sup>1</sup> with three *Swift*/XRT monitoring campaigns providing the first year-long high-sensitivity soft X-ray coverage of IGR J08408–4503, IGR J16328–4726, and IGR J16465–4507. These three SFXTs, which we shall call the *new monitoring sample*, are probably the least studied among the SFXT population, hence the interest on each individual source, whose long term soft X-ray properties are presented here for the first time. These sources also show the lowest hard X-ray duty cycles (Ducci et al. 2010; Paizis & Sidoli 2014). In Sections 2 and 3 we introduce our new monitoring sample, the observing strategy, and the analysis of both the new data and the archival ones on the initial and orbital monitoring samples. In Sect. 4 we exploit the long baseline to calculate the soft X-ray inactivity duty cycle and perform intensity-selected spectral analysis of the new monitoring sample. We also create the differential distributions of flux and luminosity for the whole SFXT sample (10 sources) searching for clues on the underlying emission mechanisms. In Sect. 5 we discuss our findings and in Sect. 6 we summarise our results and draw our conclusions.

## 2. Sample and Observations

The monitoring campaign commenced on 2011 October 20 with a focus on IGR J08408–4503 and IGR J16328–4726 for one solar year, and continued in 2013 with one year on IGR J16465–4507. Given our preliminary results at the end of 2012, we also collected further data on IGR J16328–4726 during 2013 to improve the statistics.

The transient IGR J08408–4503 (hereon J08408) was discovered on 2006 May 15 during a 900 s bright flare that reached a peak flux of 250 mCrab (20–40 keV, Götz et al. 2006). It was sought in archival *INTEGRAL* observations (Mereghetti et al. 2006), which demonstrated a recurrent transient nature, with an earlier active state in 2003. The *Swift*/XRT refined position (Kennea & Campana 2006) led to an association with an

<sup>1</sup> Project web page: <http://www.ifc.inaf.it/sfxt/>.

**Table 6.** Duty cycle of inactivity.

Name (Nickname)	Limiting Rate <sup>a</sup> (0.2–10 keV) (10 <sup>-3</sup> c s <sup>-1</sup> )	Limiting $F^a$ (2–10 keV) (10 <sup>-12</sup> erg cm <sup>-2</sup> s <sup>-1</sup> )	Limiting $L^a$ (2–10 keV) (10 <sup>34</sup> erg s <sup>-1</sup> )	$\Delta T_\Sigma$ (ks)	$P_{\text{short}}$ (%)	IDC (%)	Rate $_{\Delta T_\Sigma}$ (0.2–10 keV) (10 <sup>-3</sup> c s <sup>-1</sup> )	Distance (kpc)	Ref.
<i>Initial Monitoring Sample</i>									
IGR J16479–4514 (J16479)	16	2.5	1.1	29.7	3	19	3.1±0.5	4.9	1
XTE J1739–302 (J1739)	13	1.6	0.18	71.5	10	39	4.0±0.3	2.7	1
IGR J17544–2619 (J17544)	12	1.4	0.21	69.3	10	55	2.2±0.2	3.6	1
AX J1841.0–0536 (J1841)	13	1.8	1.6	26.6	3	28	2.4±0.4	7.8±0.74	2
<i>New Monitoring Sample</i>									
IGR J08408–4503 (J08408)	17	1.9	0.26	46.6	7	67	7.2 ± 0.6	3.4±0.34	2
IGR J16328–4726 (J16328)	14	2.7	2.5	47.5	12	61	4.0 ± 0.4	6.5±3.5	3
IGR J16465–4507 (J16465)	16	2.0	4.4	3.0	0	5	14.6 ± 0.4	12.7±1.3	2
<i>Orbital Monitoring Sample</i>									
IGR J16418–4532 (J16418)	19	12.5	36	4.8	0	11	> 9.2 <sup>b</sup>	13	1
IGR J17354–3255 (J17354)	14	2.2	3.3	7.8	1	33	> 4.6 <sup>b</sup>	8.5	4
IGR J18483–0311 (J18483)	11	1.8	0.24	11.8	0	27	3.6 ± 0.8	2.83±0.05	5

**Notes.** Count rates (Col. 2) are in units of 10<sup>-3</sup> counts s<sup>-1</sup> in the 0.2–10 keV energy band. Observed fluxes (Col. 3) are in units of 10<sup>-12</sup> erg cm<sup>-2</sup> s<sup>-1</sup> and luminosities (Col. 4) in units of 10<sup>34</sup> erg s<sup>-1</sup>, both in the 2–10 keV energy band.  $\Delta T_\Sigma$  (Col. 5) is the sum of the exposures accumulated in all observations, each in excess of 900 s, where only a 3- $\sigma$  upper limit was achieved;  $P_{\text{short}}$  (Col. 6) is the percentage of time lost to short observations; IDC (Col. 7, detailed in Sect. 4.2) is the *duty cycle of inactivity*, the time each source spends undetected down to a flux limit of reported in column 3; Rate $_{\Delta T_\Sigma}$  (Col. 8, detailed in Sect. 4.3) is the observed count rate in the data for which no detections were obtained as single observations. Values for the initial monitoring sample were recalculated based on the whole length of the campaigns (Romano et al. 2011). <sup>(a)</sup> Based on a single 900 s exposure. <sup>(b)</sup> 3- $\sigma$  upper limit.

**References.** (1) Rahoui et al. (2008); (2) Coleiro et al. (2013); (3) Fionchi et al. (2013, 3–10 kpc); (4) Tomsick et al. (2009); (5) Torrejón et al. (2010).

O8.5Ib(f) supergiant star, HD 74194, (Masetti et al. 2006) at a distance of  $\sim 3$  kpc. *Swift* caught several bright flares from this source (Romano et al. 2013a, and references therein).

The transient IGR J16328–4726 (Bird et al. 2007, hereon J16328) has a long history of hard X-ray activity characterised by flares lasting up to a few hours (Fionchi et al. 2010) as observed by *INTEGRAL*. *Swift* also caught one bright flare (Romano et al. 2013b), when the source reached an unabsorbed 2–10 keV flux of  $\sim 4 \times 10^{-10}$  erg cm<sup>-2</sup> s<sup>-1</sup>. The orbital period is  $P_{\text{orb}} = 10.076 \pm 0.003$  d (Corbet et al. 2010), and the IR/optical counterpart is 2MASS J16323791–4723409 (Grupe et al. 2009), an O8Iafpe supergiant star (Coleiro et al. 2013).

The source IGR J16465–4507 (hereon J16465) was discovered by *INTEGRAL* on 2004 September 6–7, when it averaged  $8.8 \pm 0.9$  mCrab (18–60 keV) and subsequently showed a strong flare at  $\sim 28$  mCrab on September 7. It never triggered the *Swift*/BAT. IGR J16465–4507 is a pulsar with  $P_{\text{spin}} = 228 \pm 6$  s (Lutovinov et al. 2005) and orbital period  $P_{\text{orb}} = 30.243 \pm 0.035$  d (La Parola et al. 2010). The optical counterpart is 2MASS J16463526–4507045 (Zurita Heras & Walter 2004) a B0.5Ib (Negueruela et al. 2007) star at a distance of about 8 kpc (but also see Nespoli et al. 2008; Rahoui et al. 2008).

For these sources we obtained 2 observations week<sup>-1</sup> object<sup>-1</sup>, each 1 ks long. The XRT mode was set in AUTO for J08408 and J16328 to best exploit XRT automatic mode switching (Hill et al. 2004) in response to changes in the observed fluxes, and in photon counting (PC) mode for J16465. The observation logs are reported in Tables<sup>2</sup> 1, 2, and 3. We also considered data obtained while J08408, J16328, and J1841.0 were

in outburst to include in our count rate distributions (Table<sup>3</sup> 4). During this new monitoring campaign we collected a total of 245 *Swift* observations as part of our program, for a total net XRT exposure of  $\sim 221$  ks accumulated on the three sources and distributed as shown in Table 5.

### 2.1. Reanalysis of the initial and orbital monitoring samples

We considered the data on the initial monitoring sample, J16479, J1739, and J17544, collected during the first two years of monitoring (Romano et al. 2011, 2007-10-26 to 2009-11-03), and those on J1841 collected during the first year of monitoring (Romano et al. 2009, 2007-10-26 to 2008-11-15). We also considered the data on the orbital monitoring sample, J18483 (Romano et al. 2010, 2009-06-11 to 2009-07-08), J16418 (Romano et al. 2012b, 2011-02-18 to 2011-07-30), and J17354 (Ducci et al. 2013, 2012-07-18 to 2012-07-28).

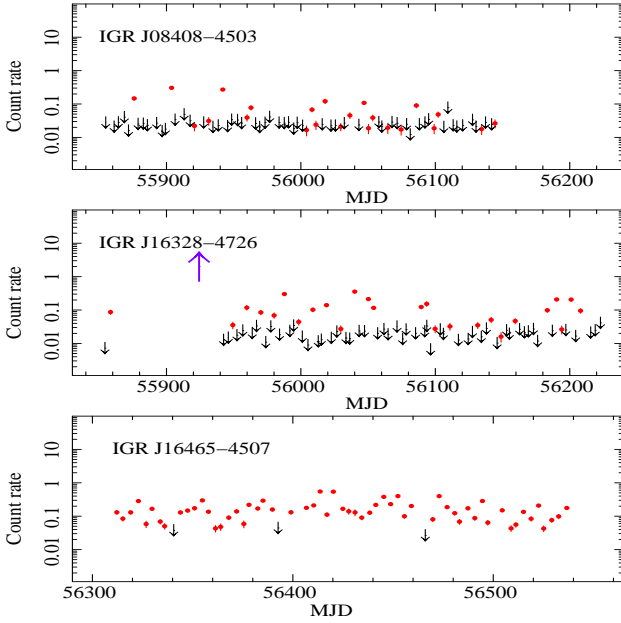
We reanalyzed them by using the most recent software and calibrations like the newly acquired data, as described below.

## 3. Data reduction

The XRT data were processed with standard procedures (XRT-PIPELINE v0.12.6), filtering and screening criteria by using FTOOLS (v6.13). During the monitoring campaigns the source count rates never exceeded  $\sim 0.5$  count s<sup>-1</sup>, so only PC events (selected in grades 0–12) were considered. Source events were accumulated within a circular region with an outer radius of 20 pixels (1 pixel  $\sim 2.36''$ ). Background events were accumulated from an annular source-free region centered on J08408 (in-

<sup>2</sup> Online only.

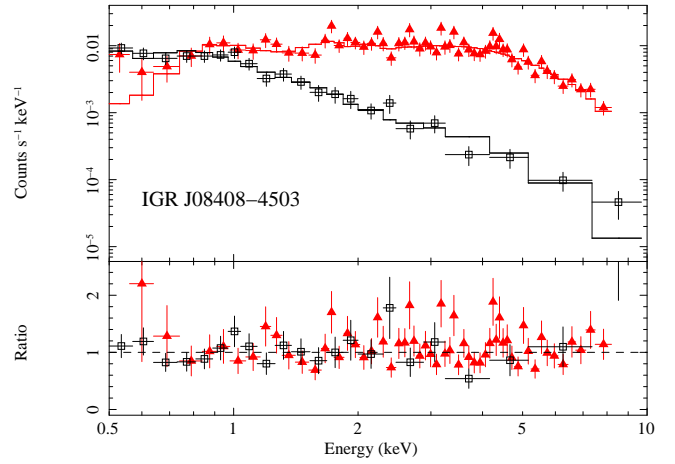
<sup>3</sup> Online only.



**Fig. 1.** *Swift*/XRT (0.2–10 keV) light curves. The data were collected from 2011 October 20 to 2012 October 22 and from 2013 January 20 to October 24. The (black) downward-pointing arrows are  $3\sigma$  upper limits. The upward pointing arrow marks a flare that triggered the BAT on MJD 55924 (2011 December 29).

ner/outer radii of 100/160 pixels), and on J16465 (inner/outer radii of 80/120 pixels), and from a nearby source-free circular region (80 pixels) for J16328. The data obtained during outbursts to include in the count rate distributions were affected by pile-up, and were corrected by adopting standard procedures (Vaughan et al. 2006; Romano et al. 2006). The outburst data, reported in Table 4, come from the 2013 July 2 outburst for J08408 (Romano et al. 2013a), the 2009 June 10 one for J16328 (Romano et al. 2013b), and the 2012 June 14 one for J1841 (Romano et al. 2013c). For our spectral analysis, we extracted events in the same regions as those adopted for the light curve creation; ancillary response files were generated with `XRTMKARF`, to account for different extraction regions, vignetting, and PSF corrections. We used the latest spectral redistribution matrices in CALDB (20130313). For a more detailed discussion of the data analysis procedure, we refer the reader to Romano et al. (2011, and references therein).

The BAT data of the outburst of 2011 December 29 06:39:20 UT (image trigger number 510701)<sup>4</sup> of J16328 were analyzed using the standard BAT software within `FTOOLS`. The source is not detected above  $\geq 70$  keV. The BAT mask-weighted spectrum was extracted during the first orbit of data; an energy-dependent systematic error vector was applied and response matrices were generated with `BATDRMGEN`. The spectrum was fit in the 15–70 keV range with a simple power law, obtaining  $\Gamma_{\text{BAT } 2011} = 3.0 \pm 1.0$  ( $\chi^2_\nu = 1.162$ , 37 d.o.f.). The 20–50 keV flux was  $2.8 \times 10^{-10}$  erg cm<sup>-2</sup> s<sup>-1</sup>.



**Fig. 2.** Spectroscopy of the 2011–2012 campaign on J08408. Red filled triangles and black empty squares mark low and very low states, respectively. *Top panel:* XRT data fit with an absorbed power law and blackbody. *Bottom panel:* the data/model ratio.

## 4. Results

### 4.1. Soft X-ray light curves and dynamical ranges

The 0.2–10 keV XRT light curves are shown in Fig. 1. They are corrected for PSF losses and vignetting, and background-subtracted. Each point in the light curves refers to the average count rate observed during each observation performed with XRT. Hereon errors on count rates are at the  $1\sigma$  level.

The dynamic range (DR), which we shall define as the maximum to minimum ratio, in count rate units, is probably the simplest piece of information we can measure from the X-ray light curves. Its knowledge has, however, quite a large impact in our understanding a source, since it can be used to discriminate (Negueruela et al. 2006b; Walter et al. 2006) between outbursts of classical supergiant HMXB (sgHMXB,  $\lesssim 50$ ) and SFXT ( $\gtrsim 100$ ).

For each source we calculated the observed XRT DR during this monitoring when considering individual detections,  $3\sigma$  upper limits, and the peak count rate ever observed by XRT. For J08408 we obtain a minimum DR of 25 (the maximum value being  $\sim 0.3$  counts s<sup>-1</sup>, the minimum a  $3\sigma$  upper limit at 0.012 counts s<sup>-1</sup>). The overall DR, considering the recorded outbursts (Romano et al. 2013a, and references therein) reaches then about 2000. J16328 reaches a DR in excess of 50 (the maximum value being  $\sim 0.3$  counts s<sup>-1</sup>, the minimum a  $3\sigma$  upper limit at 0.01 counts s<sup>-1</sup>). The overall DR, considering the recorded outburst (Romano et al. 2013b, maximum at  $\sim 3$  counts s<sup>-1</sup>) then is of the order of  $\sim 500$ . J16465 was detected in all observations except 3, and shows a DR of 12, the peak being 0.55 counts s<sup>-1</sup>. The DR only increases to 20 if individual  $3\sigma$  upper limits are considered (the lower being 0.026 counts s<sup>-1</sup>), as this source never triggered the BAT. By considering the detections obtained by combining all data for each source where individual observations only yielded  $3\sigma$  upper limits (see below Section 4.2 and Col. 8 in Table 6), the overall DR are  $\sim 7400$ ,  $\sim 750$ , and 38, for J08408, J16328, and J16465, respectively.

### 4.2. Soft X-ray inactivity duty cycle

Our monitoring pace ensures a casual sampling of the X-ray light curve at a resolution of  $\sim 3$ –4 d over a  $\sim 1$  yr baseline, so

<sup>4</sup> See Romano et al. (2013b) for an analysis of the 2009 June 10 outburst.

**Table 7.** XRT spectroscopy of the three SFXTs in the new monitoring sample (2011–2013 data set).

Name	Spectrum	Mean Rate (c s <sup>-1</sup> )	$N_{\text{H}}$ (10 <sup>22</sup> cm <sup>-2</sup> )	$\Gamma$	$kT_{\text{BB}}$ (eV)	$R_{\text{BB}}$ (km)	Flux <sup>a</sup> (2–10 keV) (10 <sup>-12</sup> )	Luminosity <sup>b</sup> (2–10 keV) (10 <sup>35</sup> )	$\chi^2_{\nu}/\text{dof}$	F-test <sup>c</sup> $p$	Fig.
J08408	low	0.05	0.30 <sup>+0.16</sup> <sub>-0.30</sub>	0.44 <sup>+0.13</sup> <sub>-0.09</sub>	–	–	5.6	0.078	1.7/57		
	low	0.05	1.54 <sup>+0.50</sup> <sub>-0.47</sub>	1.02 <sup>+0.26</sup> <sub>-0.25</sub>	69 <sup>+14</sup> <sub>-11</sub>	(9.5 <sup>+56.0</sup> <sub>-7.9</sub> ) × 10 <sup>2</sup>	5.5	0.076	1.18/55	4.4 × 10 <sup>-5</sup>	2
	very low <sup>d</sup>	0.009	0.30 <sup>+0.00</sup> <sub>-0.30</sub>	3.24 <sup>+0.18</sup> <sub>-0.18</sub>	–	–	0.09	0.001	1.47/194		
	very low <sup>d</sup>	0.009	0.30 <sup>+0.11</sup> <sub>-0.30</sub>	1.98 <sup>+0.31</sup> <sub>-0.32</sub>	99 <sup>+13</sup> <sub>-12</sub>	15 <sup>+11</sup> <sub>-5</sub>	0.19	0.003	1.18/192	6.9 × 10 <sup>-10</sup>	2
J16328	low	0.08	13.56 <sup>+1.82</sup> <sub>-1.61</sub>	1.35 <sup>+0.28</sup> <sub>-0.26</sub>	–	–	16	1.4	0.84/110		3
	very low <sup>e</sup>	0.007	1.54 <sup>+0.99</sup> <sub>-1.54</sub>	0.30 <sup>+0.39</sup> <sub>-0.22</sub>	–	–	1.1	0.06	1.66/242		
	very low	0.007	4.37 <sup>+1.78</sup> <sub>-1.50</sub>	1.01 <sup>+0.52</sup> <sub>-0.48</sub>	46 <sup>+20</sup> <sub>-13</sub>	(7.9 <sup>+30.0</sup> <sub>-7.8</sub> ) × 10 <sup>5</sup>	0.95	0.06	1.12/240	3.1 × 10 <sup>-21</sup>	3
J16465	high	>0.25	2.76 <sup>+0.39</sup> <sub>-0.35</sub>	1.05 <sup>+0.16</sup> <sub>-0.15</sub>	–	–	43	9.7	1.02/108		
	high	>0.25	3.02 <sup>+0.43</sup> <sub>-0.38</sub>	1.13 <sup>+0.16</sup> <sub>-0.16</sub>	51 <sup>+32</sup> <sub>-11</sub>	(2.3 <sup>+36.0</sup> <sub>-2.3</sub> ) × 10 <sup>5</sup>	43	9.8	0.93/106	7.5 × 10 <sup>-3</sup>	4
	medium [0.15–0.25]	2.04 <sup>+0.37</sup> <sub>-0.32</sub>	0.90 <sup>+0.16</sup> <sub>-0.15</sub>	–	–	–	23	5.0	1.18/102		
	medium [0.15–0.25]	3.53 <sup>+0.98</sup> <sub>-0.86</sub>	1.28 <sup>+0.25</sup> <sub>-0.24</sub>	12 <sup>+3</sup> <sub>-3</sub>	(5.9 <sup>+19.0</sup> <sub>-4.5</sub> ) × 10 <sup>2</sup>	–	22	5.3	1.04/100	1.8 × 10 <sup>-3</sup>	4
	low	<0.15	2.26 <sup>+0.28</sup> <sub>-0.26</sub>	1.42 <sup>+0.14</sup> <sub>-0.14</sub>	–	–	8.0	1.8	1.32/120		
	low	<0.15	2.56 <sup>+0.32</sup> <sub>-0.30</sub>	1.52 <sup>+0.15</sup> <sub>-0.15</sub>	55 <sup>+11</sup> <sub>-9</sub>	(3.4 <sup>+15.0</sup> <sub>-2.8</sub> ) × 10 <sup>4</sup>	7.9	1.8	1.17/118	8.1 × 10 <sup>-4</sup>	4

**Notes.** Uncertainties are given at 90 % confidence level for one interesting parameter. <sup>(a)</sup> Average observed 2–10 keV fluxes in units of 10<sup>-12</sup> erg cm<sup>-2</sup> s<sup>-1</sup>. <sup>(b)</sup> Average 2–10 keV luminosities in units of 10<sup>35</sup> erg s<sup>-1</sup> calculated by adopting the distances of Table 6. <sup>(c)</sup> F-test probability for the addition of the blackbody component (previous line). <sup>(d)</sup> Fit performed with a column density constrained to be larger than the one derived from optical extinction towards the optical counterpart (see Sect 4.3). <sup>(e)</sup> Fit performed with column density constrained to be larger than the Galactic value (see Sect 4.3).

we can follow the procedures detailed in Romano et al. (2009, 2011), to calculate the percentage of time each source spent in each flux state. Romano et al. (2009, 2011) defined three states, *i*) BAT-detected flares, *ii*) intermediate state (all observations yielding a firm detection, outbursts excluded), *iii*) ‘non detections’ (detections with a significance below  $3\sigma$ ) with exposure in excess of 900 s (to account for non detections obtained during very short exposures due to our observations being interrupted by a higher figure-of-merit GRB event).

The duty cycle of *inactivity* is defined (Romano et al. 2009) as the time each source spends *undetected* down to a flux limit of  $1\text{--}3 \times 10^{-12}$  erg cm<sup>-2</sup> s<sup>-1</sup>,

$$\text{IDC} = \Delta T_{\Sigma} / [\Delta T_{\text{tot}} (1 - P_{\text{short}})], \quad (1)$$

where  $\Delta T_{\Sigma}$  is the sum of the exposures (each longer than 900 s) accumulated in all observations where only a  $3\sigma$  upper limit was achieved (Table 6, Col. 5),  $\Delta T_{\text{tot}}$  is the total exposure accumulated (Table 5, Col. 6), and  $P_{\text{short}}$  is the fraction of time lost to short observations (exposure < 900 s, Table 6, Col. 6). The flux limits  $1\text{--}3 \times 10^{-12}$  erg cm<sup>-2</sup> s<sup>-1</sup> (Table 6, Col. 3) are obtained by converting the limiting count rates (derived from a measurement of the local background during the whole campaigns) with a count rate to flux conversion derived from the best fit models of the ‘low’ (J08408 and J16328) and ‘medium’ (J16465) spectra in Table 7 (Sect. 4.3). For the initial sample we recalculated the values in Romano et al. (2011) based on the whole length of the campaigns. For the orbital monitoring sample we adopted the best fit to the first sequence described in Romano et al. (2012b) for J164182, the total spectrum in Ducci et al. (2013) for J17354, and the ‘medium’ spectrum in Romano et al. (2010) for J18483. Table 6 also reports the limiting luminosities (Col. 4) and the distances adopted (Col. 9).

For the new sample we obtain that IDC = 67, 61, and 5 %, for J08408, J16328, and J16465, respectively (Table 6, Col. 7).

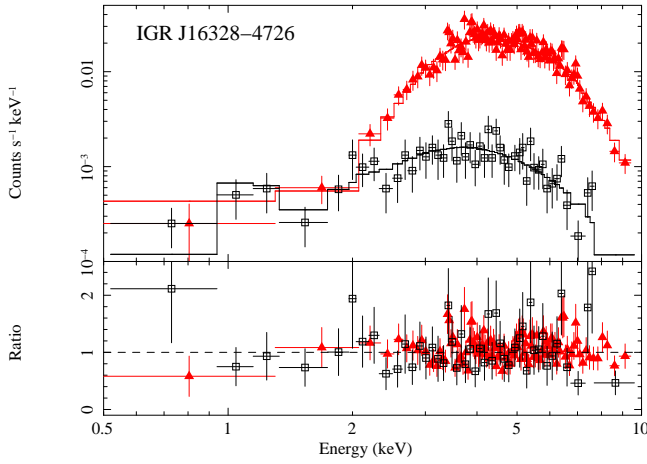
#### 4.3. Out-of-outburst X-ray spectroscopy

Let us now consider the emission outside the bright outbursts. For J08408, J16328, and J16465 (totalling about 1800, 3000, and 7600 counts, respectively) we extracted the events in each observation when a detection was achieved (point *ii*) in Sect. 4.2), thus effectively selecting an intermediate, non quiescent state, and accumulated the mean spectrum. For IGR J08408–4503 and IGR J16328–4726 we name this spectrum ‘low’ (see Table 7). For J16465, we split the events in the ranges < 0.15 counts s<sup>-1</sup> (‘low’), 0.15–0.25 counts s<sup>-1</sup> (‘medium’), and > 0.25 counts s<sup>-1</sup> (‘high’).

Furthermore, we accumulated all data for which no detections were obtained as single exposures (point *iii*) in Sect. 4.2, whose combined exposure is  $\Delta T_{\Sigma}$  and extracted spectra (‘very low’ in Table 7, ~ 300–500 counts each), we binned them to 1 count bin<sup>-1</sup>, and used Cash statistics<sup>5</sup> for the fitting. On these event lists, we performed a detection, and the resulting cumulative mean count rates are reported in Table 6 (Col. 8).

For all event lists exposure maps and ARFs were created as detailed in Romano et al. (2009). The spectra were rebinned with a minimum of 20 counts per energy bin, and fit in the 0.5–10 keV (J08408 and J16328) and 0.3–10 keV (J16465) energy ranges with a simple absorbed power-law model, and an absorbed power-law model plus a blackbody (BBODYRAD) when the residuals indicated a soft X-ray excess. In that case, the F-test probability for the addition of such component is reported in Table 7 (Col. 11) along with the fit parameters (Cols. 4–7) and their 90 % confidence level (precision) errors for one interesting parameter. We note that, given the relatively poor statistics in the soft X-ray, this thermal component is to be considered a

<sup>5</sup> See, [http://www.swift.ac.uk/xrt\\_spectra/docs.php](http://www.swift.ac.uk/xrt_spectra/docs.php).



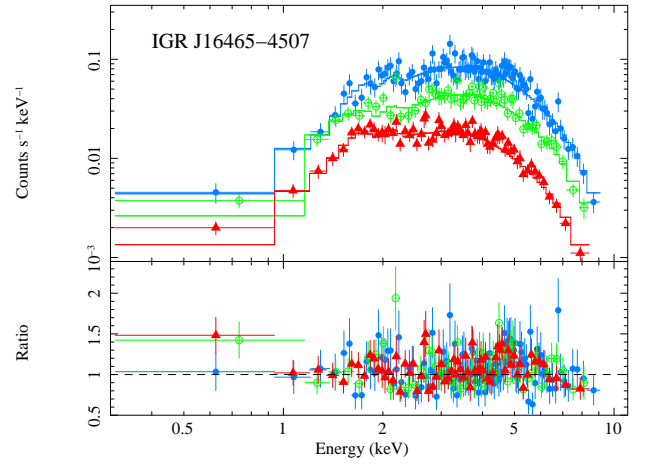
**Fig. 3.** Spectroscopy of the 2011–2013 campaign on J16328. Red filled triangles and black empty squares mark low and very low states, respectively. *Top panel:* XRT data fit with an absorbed power law (low) and absorbed power law plus blackbody (very low), respectively. *Bottom panel:* the data/model ratio.

convenient parameterization of the soft excess, rather than the modelling of a physical feature.

Figure 2 shows the best-fit spectra of J08408. The ‘low’ spectrum of J08408 is characterised by the presence of a soft ( $< 2$  keV) component in excess of a simple absorbed power-law continuum, as demonstrated by the trend for the absorption column density to peg at an unphysical null value. Even when the absorbing column is constrained to be above the value derived from the optical extinction towards the optical counterpart HD 74194,  $0.3 \times 10^{22} \text{ cm}^{-2}$  (Leyder et al. 2007), in excess of the Galactic value of  $0.932 \times 10^{22} \text{ cm}^{-2}$  (Kalberla et al. 2005), our fit is formally unacceptable (‘low’ in Table 7). Although the addition of a thermal component improves the fit ( $p = 4.4 \times 10^{-5}$ ), due to the low statistics below  $\sim 2$  keV, the black-body radius is not well constrained. Our results are consistent with those of Bozzo et al. (2010, a 26 ks *XMM-Newton* observation, col. 4 in table 3). For the ‘very low’ spectrum we obtain spectral parameters consistent with those of the fainter spectrum in Bozzo et al. (2010, col. 2 in table 3), although our  $N_H$  pegged to the Galactic value and our derived  $R_{BB}$  is significantly smaller.

Figure 3 shows the spectra of J16328. The ‘low’ spectrum is fit well by a simple absorbed power law, and is a factor of 3 fainter than the lowest state observed in the 2009 June 10 outburst (Romano et al. 2013b), and shows consistent spectral parameters. The addition of a soft component is required only for the ‘very low’ spectrum, but the blackbody radius is unconstrained. The spectra outside of outburst are relatively softer than those observed during the bright outbursts, as is generally observed for SFXTs when fitting the soft X-ray band data, only (Romano et al. 2013b). Our ‘low’ spectrum results are consistent with those of Bozzo et al. (2012, a 22 ks *XMM-Newton* observation).

Figure 4 shows the spectra of J16465. While the ‘high’ spectrum is fit adequately by a simple absorbed power law, the residuals still show a trend for an extra soft component, so further fits were performed with the addition of blackbody component. The ‘low’ spectrum has flux comparable to that of the spectrum observed by Morris et al. (2009, *Suzaku* observation) for which consistent values of absorbing column and photon index were found.



**Fig. 4.** Spectroscopy of the 2013 campaign on J16465. *Top panel:* XRT data fit with an absorbed power law plus blackbody. *Bottom panel:* the data/model ratio. Filled blue circles, green empty circles, and red filled triangles mark high, medium, and low states, respectively.

#### 4.4. Count rate, flux, and luminosity distributions

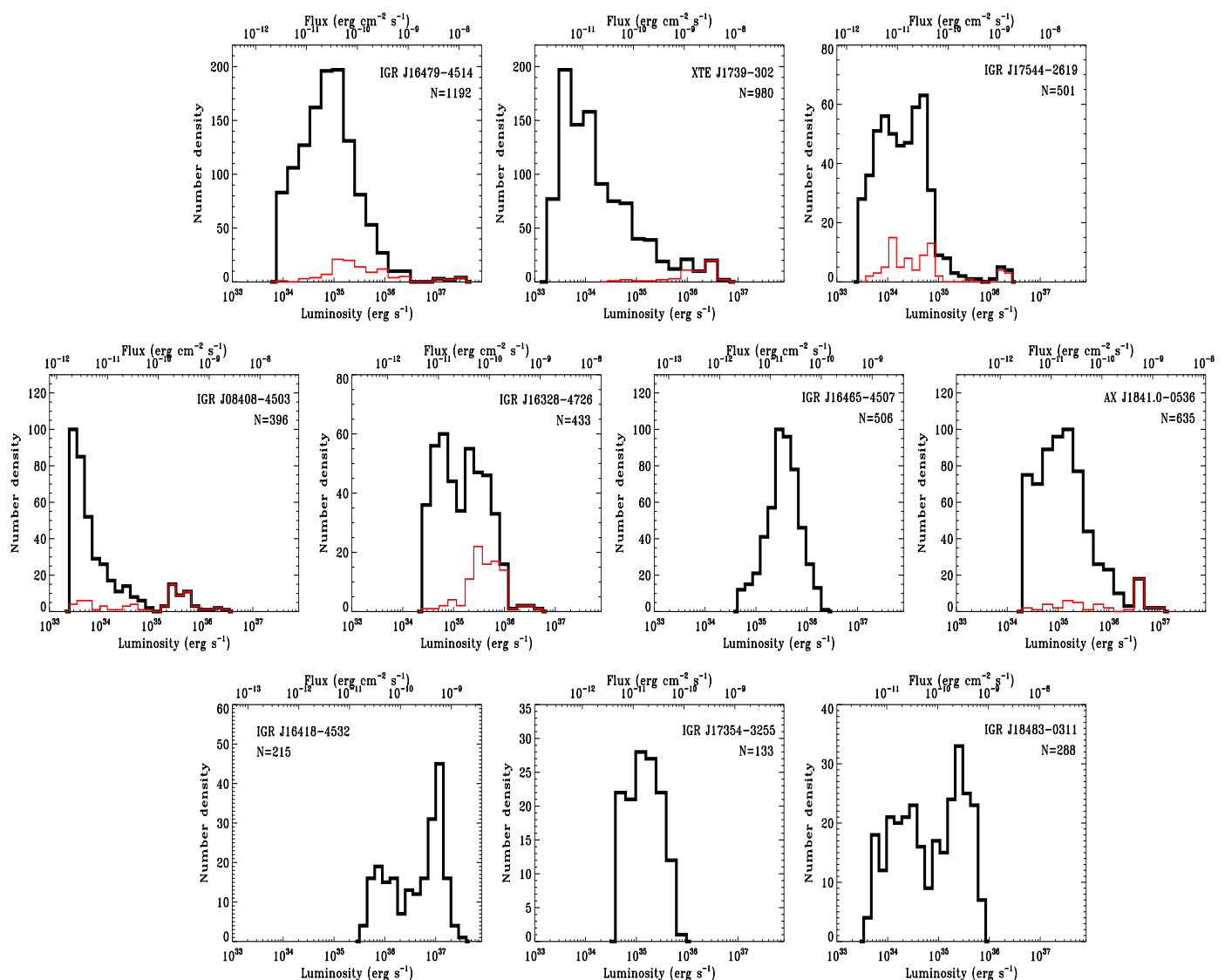
Following the procedures detailed in Romano et al. (2011), we calculate the percentage of time J08408, J16328, and J16465 spend at a given flux state. To also place their behaviour in a broader context, we applied the same procedure for both the newly processed data on the initial and for the orbital monitoring samples.

Figure 5 (black solid lines) shows the differential distributions of the 2–10 keV luminosities, drawn from the XRT light curves binned at 100 s, after removal of the observations where a detection was not achieved, ordered by length of monitoring campaign. Since the uncertainty in this conversion is dominated by those on the distance determinations, Fig. 5 also reports the flux scale (2–10 keV, unabsorbed), as the top x-axis. The conversion factors for the initial monitoring sample were those calculated in Romano et al. (2011); for the orbital monitoring sample (see Sect. 2.1) those calculated in Romano et al. (2010, 2012b) and Ducci et al. (2013). For the new monitoring sample, the conversion factors were derived from the spectroscopy in Table 7. The first row shows the reanalyzed data on the three SFXTs monitored for two years (Romano et al. 2011). We distinguish, among the data, those that were taken during an outburst (2 for J16479, and 3 for J1739 and J17544) as a thin red histogram. We note how the outburst data have one bright peak in the range  $\sim 10\text{--}70 \text{ counts s}^{-1}$  (corresponding to a few  $10^{36}\text{--}10^{37} \text{ erg s}^{-1}$ ), while the remainder spreads beneath the main peak of the luminosity distribution. This is due to the way the data were collected, as a BAT trigger follow-up, hence with a statistically very rich first orbit of data sometimes followed by an intense monitoring up to  $\sim 10$  ks per day until the source went back to the pre-outburst levels. Figure 6, which shows the count rate (CR) distributions in phase<sup>6</sup> (periods in Table 8, Col. 2), further illustrates this in the panel on J16328: the hashed histogram data were taken consecutively after a bright outburst that was followed intensively.

The second row of Fig. 5 shows the 4 sources that were monitored for one year and never went into outburst while being monitored. To assess the overall distributions, we therefore selected

<sup>6</sup> The XRT light curves were first phased at the known periods, then histogrammes were created.

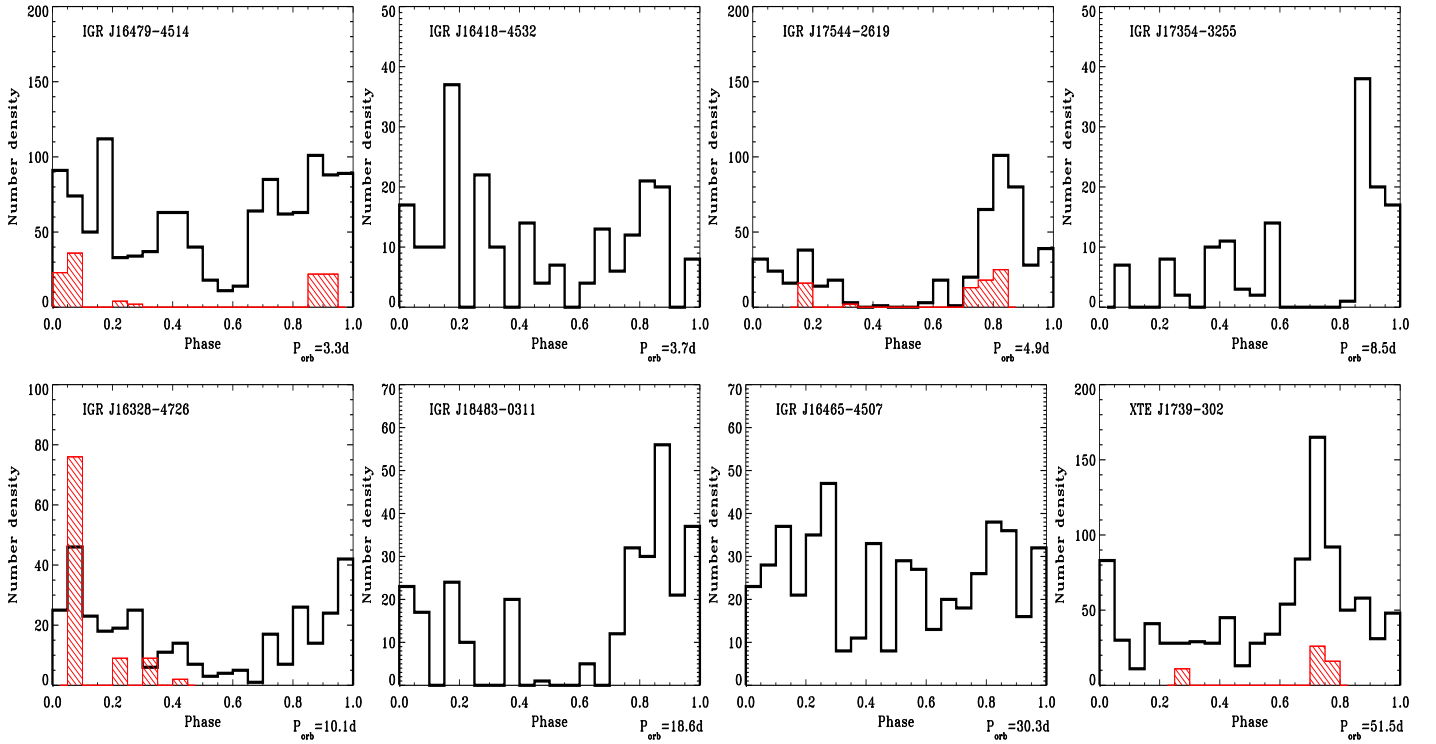




**Fig. 5.** Distributions of the XRT 2–10 keV luminosity (lower axis) and flux (unabsorbed, upper axis) drawn from the light curves binned at 100 s. *Top:* SFXTs monitored for two years (Romano et al. 2011); the thin red histograms show the part of the data collected as outburst observations thus including both the initial bright flare and the follow-up observations. *Middle:* SFXTs monitored for one year (Romano et al. 2009); the thin red histograms show outburst observations collected outside of the monitoring campaign (one outburst per source). *Bottom:* SFXTs monitored for one orbital period (Romano et al. 2010; Ducci et al. 2013; Romano et al. 2012b). The sample size,  $N$ , is reported in each panel.

one outburst and added the data as a thin red histogram. J16465 never triggered the BAT, so no data were added. For J08408 only the tail of a distribution probably peaking well below the XRT sensitivity at this binning is seen, but the outburst data clearly map another distribution, with a peak at a few counts  $s^{-1}$  and extending up to about  $\sim 50$  counts  $s^{-1}$ , corresponding to a few  $10^{35}$ – $10^{36}$  erg  $s^{-1}$ . Similarly, J1841 shows a non-outburst distribution peaking at about  $\sim 0.1$  counts  $s^{-1}$ , while the outburst data peak at a few counts  $s^{-1}$ . J16328 shows a non-outburst distribution qualitatively similar to the one observed in J1739 and J1841, but the statistics do not allow us to determine whether the outburst data fall on the tail of the main distribution or if they can be distinguished from it. Based on these findings, the most probable X-ray flux for J08408 is  $\lesssim 2 \times 10^{-12}$  erg  $cm^{-2}$   $s^{-1}$  (2–10 keV, unabsorbed), for J16328 is  $\sim 10^{-11}$  erg  $cm^{-2}$   $s^{-1}$ . These are about two orders of magnitude lower than the bright outbursts for these two sources. J16465 shows a well defined distribution peaking at  $\sim 0.1$  counts  $s^{-1}$ , corresponding to  $\sim 2 \times 10^{-11}$  erg  $cm^{-2}$   $s^{-1}$ .

The third row of Fig. 5 shows the distributions for the three SFXTs monitored for one orbital period, none of which has XRT outburst data available. We note that J18483 triggered the BAT once on 2008 August 4, but no XRT data are available. Furthermore, while J16418 triggered the BAT four times since *Swift*'s launch, one trigger did not have XRT follow-up, two were sub-threshold (and showed a light curve peaking at  $\sim 5$  counts  $s^{-1}$ ), and the last had a very late follow-up, so no data with matching quality to those of the remainder of the sample are available. These data need to be taken with caution, as they were collected with an entirely different observing strategy. Indeed, while the yearly monitoring is a casual sampling of the light curves with few points per period, these observations were collected with an intensive campaign during one or few orbital periods. Therefore the effects of short timescale variability (variations of one order of magnitude are quite common, see Romano et al. 2010, 2012b; Ducci et al. 2013) may play the dominant role in this case.



**Fig. 6.** Distribution of the XRT count rates (0.3–10 keV) folded at the orbital periods, with the sources ordered by orbital period. Color coding is the same as in Fig. 5.

The CR distributions in phase (Fig. 6) match reasonably well (considering the lower S/N in the XRT data) the BAT light curves folded at the orbital periods, as shown in Romano et al. (2014), although the eclipse troughs expected in J16479 and J16418 are less deep. This is a common occurrence in eclipsing HMXBs, and is discussed in terms of dust scattering by Bozzo et al. (2008b) and by Drave et al. (2013) for J16418 as reprocessing of the intrinsic neutron star emission by the supergiant dense wind.

## 5. Discussion

### 5.1. Soft X-ray long term properties: J16465 is not an SFXT

In this paper we report the results of a *Swift*/XRT monitoring of J08408, J16328, and J16465 along a baseline of over two years and place them in the broader context of the SFXT sample.

During the campaigns only J16328 triggered the BAT and the properties of this bright flare,  $\Gamma_{2011} = 3 \pm 1$ ,  $F_{20-50\text{ keV}} = 2.8 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$ , are consistent with those observed during the only other outburst recorded by *Swift* on this source ( $\Gamma_{2009} = 2.6 \pm 0.4$ ,  $F_{20-50\text{ keV}} = 7.1 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}$ ). Given the lack of observed outbursts during our monitoring, and considering the outburst history of the three sources, we estimate that they spend less than 1 % of their time in bright outbursts.

The main purpose of our monitoring is to exploit the unique flexibility of *Swift* to continue our characterisation of the long-term behaviour and emission outside the bright outbursts in SFXTs. J08408 and J16328 show activity at a level of 1–2 orders of magnitude lower than the bright outbursts, as previously observed for the initial monitoring sample (Romano et al. 2011, and references therein). Figure 1 shows that, when the data are binned to a daily timescale, the dynamical range (25–50) of these two SFXTs is somewhat smaller than that of the initial sample

that instead showed variations spanning more than two-orders of magnitude. Nevertheless, when we take into account the bright outbursts of J08408 and J16328 and the deep  $3\sigma$  upper limits obtained combining all non-detections, their DR increases to 7400 and 750, respectively, typical of the SFXT population. In either case, however, they do not reach the four orders of magnitude observed in the initial sample (fig. 1 in Romano et al. 2011).

The intermediate state of emission we observed from these sources during our monitoring is characterised by non-thermal emission (hence accretion onto the compact object) following the previously observed harder-when-brighter trend (e.g. Romano et al. 2011), as well as by a soft excess whose strength becomes dominant in the ‘very low’ spectra. We note that the addition of thermal components similar to the ones observed in other HMXBs (e.g. Hickox et al. 2004; van der Meer et al. 2005), and in particular in J08408 (Bozzo et al. 2010), improves the fit but, due to the low statistics below  $\sim 2 \text{ keV}$ , the parameters are often poorly constrained or unconstrained.

Our observations of J08408 and J16328 show that this intermediate state is characterised by soft X-ray flux variability observed on timescales of a few hundred seconds, as also observed in the initial and orbital monitoring samples, which is generally explained in terms of the clumpiness of the wind of the supergiant companion (e.g. Walter & Zurita Heras 2007).

For J16465, La Parola et al. (2010) reported that the BAT data show a narrow DR ( $< 10$  in the 15–50 keV band) and no flaring activity, and suggested this source is a faint supergiant HMXB, probably fed by a rather homogeneous wind, as opposed to a SFXT. Romano et al. (2014) also report a very scarce activity (detections in excess of  $5\sigma$ ) in the first 100 months of BAT data, and no outbursts in 9 years of *Swift* operations. However, more outbursts were reported by Clark et al. (2010), who instead classify this source as intermediate, and by Ducci et al. (2010). Bearing this in mind, and in light of our soft X-ray find-



**Table 8.** Duty cycles as a function of orbital periods.

Name	Orbital Period (d)	XRT IDC <sup>a</sup> (%)	XRT DC <sup>b</sup> (%)	IGR DC <sup>c</sup> (%)	IGR DC <sup>d</sup> (%)	Ref.
IGR J16479–4514	3.3193	19	1.8	2.8	2.39	1
IGR J16418–4532	3.73886	11	26	1.3	0.90	2
IGR J17544–2619	4.926	55	0.7	0.51	0.72	3
IGR J17354–3255	8.448	33	0.0	–	–	4
IGR J16328–4726	10.076	61	6.3	–	–	5
IGR J18483–0311	18.545	27	12	3.2	3.31	6
IGR J16465–4507	30.243	5	0.0	0.24	0.13	7
XTE J1739–302	51.47	39	4.1	0.83	0.89	8
AX J1841.0–0536	–	28	8.7	0.49	0.44	–
IGR J08408–4503	–	67	3.8	–	0.16	–

**Notes.** (a) Inactivity duty cycle in the 0.3–10 keV band. (b) XRT duty cycle at the *INTEGRAL* sensitivity for each object (Sect. 5.2). (c) Derived from Ducci et al. (2010), in the 20–40 keV band. (d) From Paizis & Sidoli (2014), in the 17–30 keV band.

**References.** (1) Romano et al. (2009); (2) Drave et al. (2013); (3) Clark et al. (2009); (4) D’Ai et al. (2011); (5) Corbet et al. (2010); (6) Levine & Corbet (2006); (7) La Parola et al. (2010); (8) Drave et al. (2010).

ings, we discuss J16465 separately from the other two sources in the new monitoring sample. The results of the intensity-selected soft X-ray spectroscopy of this source (Table 7) can be directly compared with those on J16479 (table 8 of Romano et al. 2011) that shows comparable luminosity levels in the high, medium and low spectra. In particular, we note both the consistency of the photon indices, when a simple absorbed power-law model is adopted, and the general trend for harder-when-brighter emission, as commonly observed in SFXTs. From this point of view, then, the spectral behaviour of J16465 is consistent with what we expect from the SFXT (as well as, of course, from the general sHMXB) population.

However, the XRT overall DR is below 40, as typical of the general HMXB population, rather than of SFXTs, and very little variability is observed on data binned at timescales of 100 s, for which a  $DR \leq 5$  is observed within one orbit. Furthermore, the histogram of the observed CR is single-peaked that, differently from the other SFXTs, does not show a secondary peak corresponding to the outburst data. The steepness of the wings of the distribution indicates that no emission is observed in excess of  $\sim 1$  counts  $s^{-1}$ . The full-width at zero intensity of the distribution is considerably less than 2 decades, while the other SFXTs exceed three orders of magnitude. Finally, the measured IDC (5 %) is at the very lower end of the observed distribution in SFXTs, since the lowest value is that of J16418. To all intents and purposes, especially in consideration of the fact that this source is not particularly absorbed and its distance is at the high end of the SFXT distribution, J16465 is a persistent source in the XRT. The current soft X-ray data seem to point toward a Vela X-1-like source (Kreykenbohm et al. 2008), as opposed to an SFXT.

We note that the discordant behaviour of J16465 with respect to that of the remainder of the *INTEGRAL* SFXT sample was also reported by Lutovinov et al. (2013). Within their proposed model for wind-fed HMXBs hosting a neutron star, they produced a theoretical hard X-ray luminosity vs. orbital period ( $P_{\text{orb}}-L_X$ ) diagram to which both ‘normal’ wind-fed HMXBs

and SFXTs are compared. While normal wind-fed HMXBs are observed to lie above the lower limit of luminosity allowed for a given period ( $L_X \sim P_{\text{orb}}^{-4/3}$ ), the SFXT population shows median luminosity beneath this curve. Therefore, the flaring observed in SFXTs can be explained within this context, provided that some mechanism, such as magnetic arrest, inhibits accretion. In the  $P_{\text{orb}}-L_X$  diagram, however, IGR J16465–4507 lies in the same allowed area as normal wind-fed HMXBs. We note that our luminosity distribution (Fig. 5) for this source reaches down to  $\geq 4 \times 10^{34}$  erg  $s^{-1}$ , and the XRT lowest detection (obtained by summing up all 3- $\sigma$  upper limits, see Sect 4.1) corresponds to  $\sim 3.8 \times 10^{34}$  erg  $s^{-1}$ . These values are much closer to the  $L_X \sim P_{\text{orb}}^{-4/3}$  limit than the *INTEGRAL* data, so it is possible that deeper observations of this source and a better determination of the distance<sup>7</sup> might just make it cross out of the allowed ranges in the  $P_{\text{orb}}-L_X$  diagram, which occur at  $\sim 10^{34}$  erg  $s^{-1}$  for a period of about 30 d (see fig. 10 of Lutovinov et al. 2013), like the remainder of the SFXT sample. If that were not the case, however, then this would add to the evidence that IGR J16465–4507 is indeed a normal wind-fed HMXB, as opposed to a SFXT.

## 5.2. Duty cycles and orbital geometry

A long-standing question in the SFXT field is whether the duty cycle is related to the orbital parameters, the period *in primis*. If the dominant source of X-ray variability in SFXTs were the properties of the binary geometry and inhomogeneity of the stellar wind from the donor star, as proposed in the clumpy wind models (e.g. in Zand 2005; Negueruela et al. 2008; Walter & Zurita Heras 2007), then we could expect generally larger IDCs for larger orbital periods. We can now address this question with high-sensitivity data.

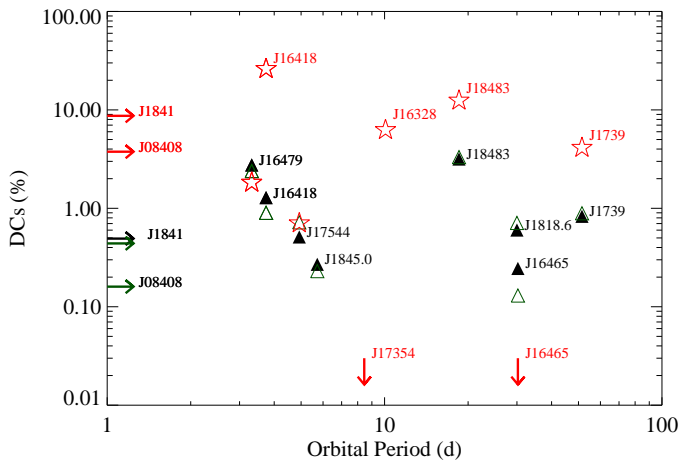
We defined the *inactivity* duty cycle (Romano et al. 2009) as the time each source spends undetected down to a flux limit of  $1-3 \times 10^{-12}$  erg  $cm^{-2}$   $s^{-1}$  (see Table 6), thus exploiting the higher XRT sensitivity when compared with hard X-ray detectors (*INTEGRAL* IBIS/ISGRI<sup>8</sup> or *Swift*/BAT<sup>9</sup>) and the regular sampling of our monitoring campaigns. The initial sample showed that these sources were actually active for the great majority of time when inspected at fluxes as low as those achievable with the high sensitivity of XRT. Similarly, our reanalysis of the data on the orbital monitoring sample shows very low IDCs (11 to 33 %). The IDCs of J08408 and J16328 (67 and 61 %, respectively) are by far the highest of the SFXT sample, as these sources are not detected for the majority of time. On the contrary, J16465 has an IDC of 5 %, which is consistent with the source being persistent.

It is interesting to compare our IDC with the DC estimated from *INTEGRAL*, whose instruments have a lower sensitivity for fainter luminosity states of the SFXTs but which can provide longer-term observations. The *INTEGRAL* IBIS/ISGRI data are presented in Ducci et al. (2010, 7 objects in common with our sample; Table 8, Col. 5), for which the most active sources are J18483 and J16479, and the least active is J16465. In Ducci et al. (2010) the duty cycle (*INTEGRAL* DC) is defined as the ratio of the time the sources are detected in excess of  $5\sigma$  and the total exposure time in the 20–40 keV band. Similar results are found when the *INTEGRAL* DCs are drawn from the recent work of

<sup>7</sup> Note that the luminosity values become  $\sim 2 \times 10^{34}$  erg  $s^{-1}$  at the distance of 9.4 kpc adopted by Lutovinov et al. (2013).

<sup>8</sup> ISGRI reaches a sensitivity (Paizis et al. 2013) of 20 mCrab in the 17–60 keV band, at the  $5\sigma$  level for 1 pointing ( $\sim 2$  ks).

<sup>9</sup> BAT reaches a sensitivity (Krimm et al. 2013) of 12.9 mCrab in the 15–50 keV band, at  $1\sigma$  level for 1 orbit ( $\sim 1$  ks).



**Fig. 7.** *INTEGRAL*-based duty cycles from Ducci et al. (2010, black filled triangles) and Paizis & Sidoli (2014, green empty triangles), and XRT duty cycle at the *INTEGRAL* sensitivity (red empty stars, Sect. 5.2). The downward pointing arrows are consistent with 0. The right pointing arrows at  $P_{\text{orb}} = 1$  are for sources lacking orbital period.

Paizis & Sidoli (2014, 8 objects in common; Table 8, Col. 6). Figure 7 shows them as a function of the orbital period. We note that our IDC is generally anti-correlated with the *INTEGRAL* DCs, with the notable exception of J16465.

Both the XRT IDC and the *INTEGRAL* DC are based on the instrumental sensitivity in the detector band. What follows is an attempt to overcome these biases. We define an *XRT luminosity-based duty cycle* (XRTDC) as the percentage of time the source spends above a given luminosity, and we considered several luminosities in the range  $L_{2-10\text{keV}} = 10^{34}-10^{36} \text{ erg s}^{-1}$ . Figure 8 shows the XRTDC as a function of the orbital period. We find that, clearly, the definition of duty cycle is strongly dependent on the luminosity assumed as lower limit for the calculation.

In particular, we can also consider the XRTDC calculated for the luminosity corresponding to the *INTEGRAL* sensitivity for each object. We considered that IBIS reaches (Paizis et al. 2013) 20 mCrab (17–60 keV) at the  $5\sigma$  level for 1 pointing ( $\sim 2$  ks), and adopted the best *Swift* broad-band spectra obtained during outburst for each object, to convert from the IBIS band and the 2–10 keV one. These points are also plotted in Fig. 8 (red stars). The XRT DCs at the *INTEGRAL* sensitivity are reported in Table 8, Col. 4. They range from  $\sim 0.7\%$  for J17544 to  $26\%$  for J16418 and there is a good match with the corresponding *INTEGRAL* values for J17544 and J16479. At the *INTEGRAL* sensitivity J16465 and J17354 have a null DC, so all emission for these sources is below this threshold.

Once the different systematics coming into play in the different definitions of duty cycles are understood, we can consider once again the relationship between the duty cycle and the binary orbital period. We find that the SFXT duty cycles are not clearly correlated with the orbital period. Therefore, wide orbits are not necessarily characterised by low duty cycles, as the clumpy wind models would predict. Instead, an intrinsic mechanism seems to be more likely responsible for the observed variability in SFXTs, i.e., either the wind properties or the compact object properties.

Finding it hard to justify radically different wind properties in SFXTs from those in ‘normal’ HMXBs with the same companion spectral type, accretion inhibition mechanisms seem more plausible, especially in light of the very low DC for J17544 (as well as the other SFXT prototype J1739), for which

Bozzo et al. (2008a) interpret the very large luminosity ranges observed on timescales as short as hours as transitions across the magnetic and/or centrifugal barriers. This is consistent with the conclusions of Lutovinov et al. (2013) that the flaring behaviour of SFXTs is likely related to the magnetic arrest of their accretion. Alternative mechanisms to partially inhibit accretion in HMXBs have been suggested by Shakura et al. (2012) and applied so far to interpret the low luminosity regimes of a number of classical supergiant X-ray binaries. The discussion of the applicability of their model to the SFXTs is beyond the scope of the present paper.

### 5.3. Differential luminosity distributions

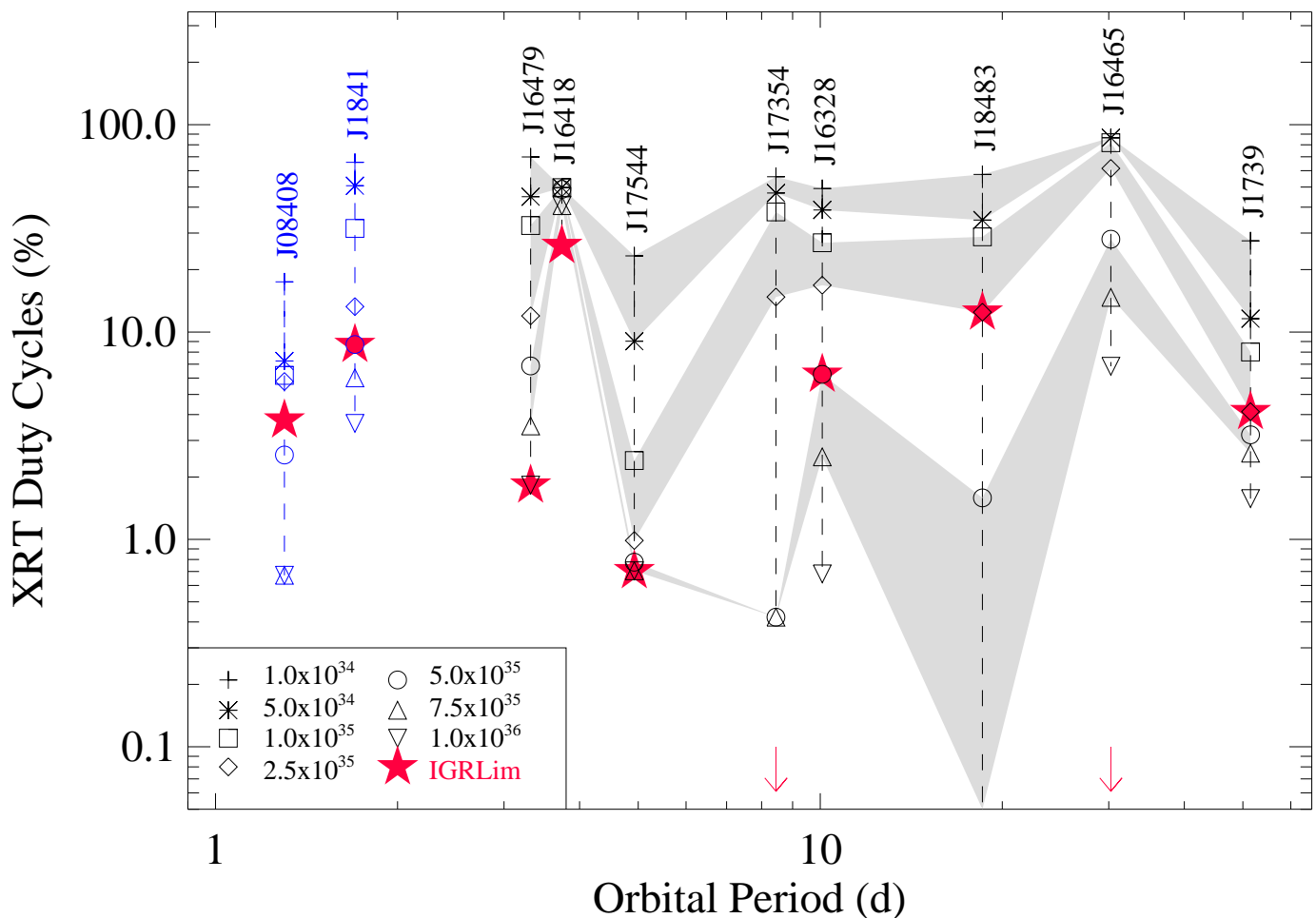
Other authors (Smith et al. 2012; Paizis & Sidoli 2014) have used the longer baseline of relatively less sensitive *RXTE* and *INTEGRAL* data available—hence geared to best detect the bright flares—to construct cumulative luminosity distributions. In this paper we exploit the higher sensitivity XRT data to construct differential count rate (flux and luminosity) distributions, instead, searching for faint features originating in different populations of flares in the soft X-ray emission. We have indeed discovered that the SFXT prototypes, J1739 and J17544, as well as J16479 and J08408, show two distinct populations of flares. The first one is due to the outburst emission and peaks (or reaches, as in the case of J08408) a few  $10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$ . The second population is due to the out-of-outburst emission, which is characterised by emission spanning up to 4 orders of magnitude in DR (at 100 s binning). While it is not possible to exclude that particular distributions of the clump and wind parameters may produce a double-peaked differential distribution, this behaviour is more easily explained in terms of different accretion regimes as predicted by the magnetic/centrifugal gating model or the quasi-spherical settling accretion model (Grebenev & Sunyaev 2007; Bozzo et al. 2008a; Shakura et al. 2012, 2013).

## 6. Summary and conclusions

In this paper we have presented the first high-sensitivity (a few  $10^{-12} \text{ erg cm}^{-2} \text{ s}^{-1}$ ) soft X-ray (0.3–10 keV) long-term ( $\gtrsim 1$  yr) monitoring with *Swift*/XRT of three relatively unexplored SFXTs, J08408, J16328, and J16465, which were chosen as those, among the SFXT sample, whose hard X-ray duty cycles are the lowest measured. We stress that our monitoring campaigns could only be performed thanks to the extraordinary flexibility in scheduling of *Swift* that makes such a monitoring effort cost-effective. Even though the single 1 ks snapshots are shallow compared to the deep observations of the other pointed observations by *XMM-Newton* or *Suzaku*, the advantages are many.

First, thanks to the regular pacing, our data provide a casual sampling of the X-ray light curves at a resolution of  $\sim 3-4$  d over a  $\sim 1$  yr baseline. They are therefore statistically representative of the long term properties of these sources that the long looks from other pointed telescopes can only sample, albeit more deeply, only rarely.

Second, these data can be used to measure two defining quantities: *i*) the dynamical range, fundamental in discriminating between outbursts of classical supergiant HMXBs ( $\lesssim 50$ ) and SFXTs ( $\gtrsim 100$ ), as described in Negueruela et al. (e.g. 2006b); Walter et al. (e.g. 2006); and *ii*) the duty cycle as a function of the luminosity across the wide dynamical range spanned by the SFXTs, which is a measure of the activity of each source, and for which different models for emission in SFXTs have contrasting predictions. We can also use the data to perform intensity-



**Fig. 8.** XRTDC (2–10 keV) as a function of orbital period and for a range of 2–10 keV luminosities (see legend, in units of  $\text{erg s}^{-1}$ ) in black. All values are also reported for J08408 and J1841, lacking an orbital period measurement, as blue data points at arbitrary orbital period below 2 days). Only points above 0.1 % are shown. The shaded areas mark the loci of XRTDC defined with contiguous luminosities. The red filled stars represent the XRT DC at the *INTEGRAL* sensitivity for each object (the downward pointing arrows are consistent with 0).

selected spectroscopy by combining all short exposures, thus reaching the same intrinsic luminosities as those reached by the long looks, thus confirming their results.

In this work, we not only created long term light curves, calculated dynamical ranges and duty cycles, spectroscopically studied the out-of-outburst emission, and created differential luminosity distributions for 3 new sources, but we also compared these properties with those of the remainder of the SFXT sample. Our findings can be summarized as follows.

- All SFXTs share out-of-outburst spectroscopic properties of non-thermal emission plus a soft excess (becoming increasingly more dominant as the source reaches the lowest emission states) with the general population of supergiant HMXBs. The spectroscopic investigation, therefore, is not an efficient method of distinguishing SFXTs within the HMXB sample.
- The behaviour of J08408 and J16328 resembles those of the SFXT prototypes: the probable X-ray flux is about two orders of magnitude lower than their bright outbursts, accounting for less than 1 % of the total time; the overall dynamical range is  $\text{DR} \sim 7400$  and  $\sim 750$ , respectively; the IDC is  $\sim 67$

and 61 %, respectively, the highest in the SFXTs observed by XRT, consistently with the hard X-ray observations.

- J16465 is to all intents and purposes a persistent source in the XRT, as opposed to an SFXT, with its overall  $\text{DR} \leq 40$  and a duty-cycle of inactivity of 5 %.
- By examining the differential luminosity distributions of the SFXT sample, we find that J17544, J1739, J16479, and J08408, show two distinct populations of flares, one due to the outbursts, one due to the out-of-outburst emission, which is characterised by fluxes spanning up to 4 orders of magnitude in DR.
- By exploiting the higher sensitivity afforded by the *Swift*/XRT observations and by correcting for the sensitivity bias, we find no correlation between the orbital period with any of the duty cycle/activity measurements defined in the soft and hard X-rays. This implies that wide orbits are not characterised by low duty cycles, thus answering a long-standing question in SFXT modelling.
- The last two findings can be interpreted in terms of mechanisms regulating or inhibiting accretion, such as a propeller effect, magnetic gating, or hot shells of accreted material above the magnetosphere.

- The definition of duty cycle is dramatically dependent on the luminosity assumed as lower limit for the calculation.
- Our differential count rate distributions indicate that, in order to observe most of the activity of an SFXT, limiting fluxes of at least a decade lower than the sensitivities reached by hard X-ray monitors need to be reached.

Our observations therefore demonstrate that soft X-ray monitoring campaigns on SFXTs, highly variable sources unpredictably going into outburst, can contribute key ingredients, such as dynamical ranges, duty cycles, and luminosity distributions, towards characterising them among the general HMXB population. In particular, given the  $\sim 10^{-12}$  erg cm $^{-2}$  s $^{-1}$  sensitivity reached in  $\sim 1$  ks by the XRT they are uniquely suited to observe most of the activity of an SFXT. They also show that the most effective way to highlight the SFXT nature of a source is the combination of the soft X-ray inactivity duty cycle and dynamical range.

Finally, we note that, in order to make significant progress towards understanding SFXTs as a class and within the HMXB context, it is of fundamental importance to continue along this line of investigation, by securing long-term soft X-ray data on more SFXTs. The fallout of such investigation will be twofold: on one side, we shall obtain an increased knowledge on a larger number of individual SFXTs, which are on average fainter than the HMXB population and often located in crowded, heavily absorbed regions of the sky, and therefore have not received adequate attention from lower sensitivity soft X-ray monitors; on the other side, we can use the combination of soft X-ray inactivity duty cycle and dynamical range to select SFXT candidates among the HMXB population. In this framework, until new insight can be obtained from wide-field, high-sensitivity monitors such as those on board LOFT (Feroci et al. 2012), as recently shown by Bozzo et al. (2013) and Romano et al. (2012a), our monitoring campaigns are the only viable mean to reach the low luminosities ( $L_{2-10\text{keV}} \sim 10^{33}-10^{34}$  erg s $^{-1}$ ) required to fully characterise the SFXT phenomenology.

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**Table 1.** Observation log for IGR J08408–4503 (J08408).

Sequence	Instrument/Mode	Start time (UT) (yyyy-mm-dd hh:mm:ss)	End time (UT) (yyyy-mm-dd hh:mm:ss)	Net Exposure (s)
00037881013	XRT/PC	2011-10-20 18:36:10	2011-10-20 18:52:56	1003
00037881015	XRT/PC	2011-10-27 01:18:15	2011-10-27 01:34:56	988
00037881016	XRT/PC	2011-10-30 04:48:18	2011-10-30 05:03:58	940
00037881017	XRT/PC	2011-11-03 16:19:21	2011-11-03 16:36:57	988
00037881018	XRT/PC	2011-11-06 18:08:59	2011-11-06 18:25:57	1005
00037881019	XRT/PC	2011-11-10 23:34:00	2011-11-10 23:49:58	938
00037881020	XRT/PC	2011-11-13 20:38:38	2011-11-13 20:53:44	880
00037881021	XRT/PC	2011-11-17 18:54:18	2011-11-17 19:09:58	920
00037881022	XRT/PC	2011-11-20 19:04:48	2011-11-20 19:21:56	1023
00037881023	XRT/PC	2011-11-24 14:34:00	2011-11-24 14:35:20	65
00037881024	XRT/PC	2011-11-27 16:21:02	2011-11-27 16:36:58	935
00037881025	XRT/PC	2011-12-01 18:34:34	2011-12-01 18:51:57	1038
00037881026	XRT/PC	2011-12-04 04:21:13	2011-12-04 04:37:56	993
00037881027	XRT/PC	2011-12-08 18:46:34	2011-12-08 19:01:57	918
00037881028	XRT/PC	2011-12-11 09:31:44	2011-12-11 09:48:57	1025
00037881029	XRT/PC	2011-12-15 19:25:12	2011-12-15 19:32:48	105
00037881030	XRT/PC	2011-12-18 03:30:41	2011-12-18 03:45:56	895
00037881031	XRT/PC	2011-12-22 13:34:53	2011-12-22 13:51:56	1020
00037881032	XRT/PC	2011-12-25 18:46:59	2011-12-25 19:03:57	993
00037881033	XRT/PC	2011-12-29 02:42:43	2011-12-29 02:57:51	311
00037881034	XRT/PC	2012-01-01 15:41:57	2012-01-01 15:58:58	998
00037881035	XRT/PC	2012-01-05 09:33:53	2012-01-05 09:48:56	810
00037881036	XRT/PC	2012-01-08 12:56:20	2012-01-08 13:11:58	928
00037881037	XRT/PC	2012-01-12 11:57:42	2012-01-12 12:13:58	970
00037881038	XRT/PC	2012-01-15 19:52:01	2012-01-15 23:28:56	1020
00037881039	XRT/PC	2012-01-19 10:33:01	2012-01-19 10:48:56	950
00037881040	XRT/PC	2012-01-22 10:59:58	2012-01-22 11:13:55	822
00037881041	XRT/PC	2012-01-26 20:47:35	2012-01-26 21:03:55	968
00037881042	XRT/PC	2012-01-29 20:59:11	2012-01-29 21:15:56	988
00037881043	XRT/PC	2012-02-02 22:51:42	2012-02-02 23:07:57	963
00037881044	XRT/PC	2012-02-05 21:26:17	2012-02-05 21:42:57	983
00037881045	XRT/PC	2012-02-09 07:14:06	2012-02-09 07:31:56	1071
00037881046	XRT/PC	2012-02-12 07:22:02	2012-02-12 07:37:57	938
00037881047	XRT/PC	2012-02-16 07:43:54	2012-02-16 08:00:57	1015
00037881048	XRT/PC	2012-02-19 17:33:52	2012-02-19 17:49:57	945
00037881049	XRT/PC	2012-02-23 16:06:09	2012-02-23 16:22:55	241
00037881050	XRT/PC	2012-02-26 17:54:06	2012-02-26 18:12:57	1106
00037881051	XRT/PC	2012-03-01 15:06:06	2012-03-01 15:22:56	988
00037881052	XRT/PC	2012-03-04 18:35:29	2012-03-04 18:52:57	1036
00037881053	XRT/PC	2012-03-08 15:37:17	2012-03-08 15:49:11	695
00037881054	XRT/PC	2012-03-11 06:11:13	2012-03-11 06:23:57	755
00037881055	XRT/PC	2012-03-15 06:07:08	2012-03-15 06:23:56	993
00037881056	XRT/PC	2012-03-18 04:36:00	2012-03-18 04:52:56	1010
00037881057	XRT/PC	2012-03-22 06:42:31	2012-03-22 07:04:57	1319
00037881058	XRT/PC	2012-03-25 05:07:24	2012-03-25 05:23:57	985
00037881059	XRT/PC	2012-03-29 19:49:53	2012-03-29 20:06:56	1020
00037881060	XRT/PC	2012-04-01 00:50:59	2012-04-01 01:00:56	597
00037881061	XRT/PC	2012-04-05 09:09:22	2012-04-05 09:25:57	983
00037881062	XRT/PC	2012-04-08 16:02:24	2012-04-08 16:18:57	980
00037881063	XRT/PC	2012-04-12 16:01:18	2012-04-12 16:18:56	1058
00037881064	XRT/PC	2012-04-15 06:40:00	2012-04-15 06:55:58	935
00037881065	XRT/PC	2012-04-19 10:10:24	2012-04-19 10:26:57	983
00037881067	XRT/PC	2012-04-26 02:29:19	2012-04-26 02:43:57	875
00037881068	XRT/PC	2012-04-29 23:17:08	2012-04-29 23:34:56	1058
00037881069	XRT/PC	2012-05-03 06:01:20	2012-05-03 06:17:58	973
00037881070	XRT/PC	2012-05-06 10:55:52	2012-05-06 11:15:56	1188
00037881071	XRT/PC	2012-05-10 22:38:34	2012-05-10 22:55:57	1018
00037881072	XRT/PC	2012-05-13 05:11:24	2012-05-13 05:27:57	983

**Table 1.** continued.

Sequence	Instrument/Mode	Start time (UT) (yyyy-mm-dd hh:mm:ss)	End time (UT) (yyyy-mm-dd hh:mm:ss)	Net Exposure (s)
00037881073	XRT/PC	2012-05-17 15:01:20	2012-05-17 15:17:58	988
00037881074	XRT/PC	2012-05-20 18:25:15	2012-05-20 18:42:58	1063
00037881075	XRT/PC	2012-05-24 13:41:11	2012-05-24 13:57:57	995
00037881076	XRT/PC	2012-05-27 13:56:22	2012-05-27 14:13:55	1033
00037881077	XRT/PC	2012-05-31 14:26:44	2012-05-31 14:42:57	953
00037881078	XRT/PC	2012-06-03 08:13:33	2012-06-03 08:30:56	1033
00037881079	XRT/PC	2012-06-07 20:53:54	2012-06-07 21:07:56	832
00037881080	XRT/PC	2012-06-10 03:28:56	2012-06-10 03:45:57	1018
00037881081	XRT/PC	2012-06-14 07:08:52	2012-06-14 07:25:58	1000
00037881082	XRT/PC	2012-06-17 00:50:04	2012-06-17 01:06:57	1003
00037881083	XRT/PC	2012-06-21 02:45:18	2012-06-21 03:01:56	988
00037881084	XRT/PC	2012-06-24 02:52:54	2012-06-24 03:10:55	1066
00037881085	XRT/PC	2012-06-28 07:37:08	2012-06-28 07:52:56	930
00037881086	XRT/PC	2012-07-01 07:48:02	2012-07-01 07:50:55	163
00037881087	XRT/PC	2012-07-05 06:20:36	2012-07-05 06:36:56	965
00037881088	XRT/PC	2012-07-08 00:25:31	2012-07-08 00:41:54	980
00037881089	XRT/PC	2012-07-12 08:26:35	2012-07-12 08:44:55	1096
00037881091	XRT/PC	2012-07-19 15:39:17	2012-07-19 15:55:55	998
00037881092	XRT/PC	2012-07-22 06:14:22	2012-07-22 06:29:55	913
00037881093	XRT/PC	2012-07-26 11:14:45	2012-07-26 11:31:56	1031
00037881094	XRT/PC	2012-07-29 07:50:40	2012-07-29 08:05:56	903
00037881095	XRT/PC	2012-08-02 21:00:51	2012-08-02 21:18:55	1078
00037881096	XRT/PC	2012-08-05 10:03:45	2012-08-05 10:20:56	1008



**Table 2.** Observation log for IGR J16328–4726 (J16328).

Sequence	Instrument/Mode	Start time (UT) (yyyy-mm-dd hh:mm:ss)	End time (UT) (yyyy-mm-dd hh:mm:ss)	Net Exposure (s)
00032126001	XRT/PC	2011-10-20 04:40:25	2011-10-20 04:55:58	913
00032126002	XRT/PC	2011-10-24 08:04:20	2011-10-24 08:19:55	933
00510701000	BAT/evt	2011-12-29 06:35:28	2011-12-29 06:55:30	1202
00032126003	XRT/PC	2012-01-16 10:57:12	2012-01-16 11:13:58	993
00032126004	XRT/PC	2012-01-19 22:29:53	2012-01-19 23:59:57	850
00032126005	XRT/PC	2012-01-23 08:23:46	2012-01-23 08:39:34	920
00032126006	XRT/PC	2012-01-26 09:58:36	2012-01-26 10:13:56	910
00032126007	XRT/PC	2012-01-30 18:14:47	2012-01-30 18:30:57	968
00032126008	XRT/PC	2012-02-02 18:26:21	2012-02-02 18:41:56	915
00032126009	XRT/PC	2012-02-06 18:38:59	2012-02-06 18:55:57	1010
00032126010	XRT/PC	2012-02-09 23:39:26	2012-02-09 23:54:57	923
00032126011	XRT/PC	2012-02-13 04:51:22	2012-02-13 05:05:42	855
00032126012	XRT/PC	2012-02-16 20:50:14	2012-02-16 21:06:56	995
00032126013	XRT/PC	2012-02-20 14:40:38	2012-02-20 14:55:58	910
00032126014	XRT/PC	2012-02-23 00:30:09	2012-02-23 02:19:57	943
00032126015	XRT/PC	2012-02-27 02:30:04	2012-02-27 02:47:57	1051
00032126016	XRT/PC	2012-03-01 13:51:34	2012-03-01 21:49:55	1271
00032126017	XRT/PC	2012-03-05 18:49:05	2012-03-05 19:06:56	1058
00032126018	XRT/PC	2012-03-08 14:08:34	2012-03-08 14:13:02	258
00032126019	XRT/PC	2012-03-12 08:02:31	2012-03-12 08:18:57	978
00032126020	XRT/PC	2012-03-15 00:28:34	2012-03-15 00:48:45	1204
00032126021	XRT/PC	2012-03-19 05:37:01	2012-03-19 05:53:57	995
00032126022	XRT/PC	2012-03-22 21:36:57	2012-03-22 21:53:58	998
00032126023	XRT/PC	2012-03-26 20:29:03	2012-03-26 23:44:57	1103
00032126024	XRT/PC	2012-03-29 04:40:21	2012-03-29 04:56:59	983
00032126025	XRT/PC	2012-04-02 01:29:38	2012-04-02 01:44:56	918
00032126026	XRT/PC	2012-04-05 14:23:29	2012-04-05 14:41:58	1091
00032126027	XRT/PC	2012-04-09 17:51:39	2012-04-09 18:04:56	777
00032126028	XRT/PC	2012-04-12 16:30:58	2012-04-12 16:48:57	1078
00032126029	XRT/PC	2012-04-16 05:26:59	2012-04-16 18:47:58	1103
00032126030	XRT/PC	2012-04-19 05:36:36	2012-04-19 09:11:58	913
00032126031	XRT/PC	2012-04-23 01:23:42	2012-04-23 01:31:56	484
00032126032	XRT/PC	2012-04-26 07:51:05	2012-04-26 08:06:58	940
00032126033	XRT/PC	2012-04-30 08:07:44	2012-04-30 08:23:56	953
00032126034	XRT/PC	2012-05-03 05:05:51	2012-05-03 05:23:57	1068
00032126035	XRT/PC	2012-05-07 02:12:05	2012-05-07 02:30:56	1131
00032126036	XRT/PC	2012-05-10 02:29:00	2012-05-10 02:44:58	958
00032126037	XRT/PC	2012-05-14 18:28:13	2012-05-14 18:43:56	935
00032126038	XRT/PC	2012-05-17 20:14:07	2012-05-17 20:29:57	940
00032126040	XRT/PC	2012-05-24 11:03:27	2012-05-24 11:18:57	915
00032126041	XRT/PC	2012-05-28 15:59:18	2012-05-28 16:12:56	800
00032126042	XRT/PC	2012-05-31 06:30:50	2012-05-31 06:46:58	955
00032126043	XRT/PC	2012-06-04 06:43:13	2012-06-04 07:00:56	1043
00032126044	XRT/PC	2012-06-07 07:05:48	2012-06-07 07:21:56	955
00032126045	XRT/PC	2012-06-11 12:07:27	2012-06-11 12:22:57	930
00032126046	XRT/PC	2012-06-14 02:34:48	2012-06-14 02:52:56	1083
00032126047	XRT/PC	2012-06-18 10:50:15	2012-06-18 11:06:58	995
00032126048	XRT/PC	2012-06-21 20:46:47	2012-06-21 21:04:58	1083
00032126049	XRT/PC	2012-06-25 16:15:52	2012-06-25 16:31:55	953
00032126050	XRT/PC	2012-06-28 00:12:14	2012-06-28 00:18:10	344
00042949001	XRT/PC	2012-06-15 14:11:10	2012-06-15 14:20:57	582
00042950001	XRT/PC	2012-06-15 15:47:08	2012-06-15 15:56:57	574
00032126051	XRT/PC	2012-07-02 21:20:06	2012-07-02 21:36:54	1005
00032126053	XRT/PC	2012-07-09 04:04:07	2012-07-09 04:20:55	1000
00032126055	XRT/PC	2012-07-16 10:58:03	2012-07-16 11:15:54	1061
00032126056	XRT/PC	2012-07-19 14:21:55	2012-07-19 14:39:56	1073
00032126057	XRT/PC	2012-07-23 11:28:27	2012-07-23 13:18:54	1204
00032126058	XRT/PC	2012-07-26 04:55:06	2012-07-26 05:08:53	805

**Table 2.** continued.

Sequence	Instrument/Mode	Start time (UT) (yyyy-mm-dd hh:mm:ss)	End time (UT) (yyyy-mm-dd hh:mm:ss)	Net Exposure (s)
00032126059	XRT/PC	2012-07-30 00:14:53	2012-07-30 00:29:56	898
00032126060	XRT/PC	2012-08-02 13:19:17	2012-08-02 13:35:55	983
00032126061	XRT/PC	2012-08-06 23:02:02	2012-08-06 23:19:55	1058
00032126062	XRT/PC	2012-08-09 21:48:59	2012-08-09 22:06:55	1066
00032126063	XRT/PC	2012-08-13 23:42:50	2012-08-13 23:59:55	1013
00032126064	XRT/PC	2012-08-16 02:52:13	2012-08-16 03:08:54	978
00032126065	XRT/PC	2012-08-20 11:11:08	2012-08-20 11:29:54	1106
00032126066	XRT/PC	2012-08-23 16:12:42	2012-08-23 16:33:54	1256
00032126067	XRT/PC	2012-08-27 06:48:58	2012-08-27 07:03:55	893
00032126068	XRT/PC	2012-08-30 05:20:38	2012-08-30 05:34:56	837
00032126069	XRT/PC	2012-09-03 00:45:13	2012-09-03 01:00:56	928
00032126070	XRT/PC	2012-09-06 02:27:30	2012-09-06 02:42:55	918
00032126072	XRT/PC	2012-09-13 07:34:36	2012-09-13 07:49:54	913
00032126073	XRT/PC	2012-09-17 01:21:14	2012-09-17 01:34:54	802
00032126074	XRT/PC	2012-09-20 04:39:22	2012-09-20 06:24:55	1008
00032126075	XRT/PC	2012-09-24 01:39:44	2012-09-24 01:54:54	903
00032126076	XRT/PC	2012-09-27 02:14:04	2012-09-27 02:26:56	760
00032126077	XRT/PC	2012-10-01 00:36:54	2012-10-01 00:50:54	820
00032126078	XRT/PC	2012-10-04 10:14:26	2012-10-04 10:30:54	965
00032126079	XRT/PC	2012-10-08 00:56:38	2012-10-08 01:08:55	730
00032126081	XRT/PC	2012-10-15 14:10:22	2012-10-15 14:26:55	978
00032126082	XRT/PC	2012-10-18 22:24:46	2012-10-18 22:40:54	955
00032126083	XRT/PC	2012-10-22 21:04:31	2012-10-22 21:09:54	308
00032126084	XRT/PC	2013-09-02 02:39:41	2013-09-02 02:56:54	1025
00032126085	XRT/PC	2013-09-05 13:55:41	2013-09-05 14:13:54	1083
00032126086	XRT/PC	2013-09-09 06:22:31	2013-09-09 06:38:57	298
00032126087	XRT/PC	2013-09-12 12:31:55	2013-09-12 12:47:48	940
00032126088	XRT/PC	2013-09-16 12:45:00	2013-09-16 12:59:55	893
00032126089	XRT/PC	2013-09-19 00:03:17	2013-09-19 00:17:56	815
00032126090	XRT/PC	2013-09-23 06:19:13	2013-09-23 06:34:53	920
00032126091	XRT/PC	2013-09-26 20:47:21	2013-09-26 21:01:54	855
00032126092	XRT/PC	2013-09-30 09:58:40	2013-09-30 10:16:55	1096
00032126093	XRT/PC	2013-10-03 01:57:38	2013-10-03 02:14:54	860
00032126094	XRT/PC	2013-10-07 14:51:09	2013-10-07 15:06:54	938
00032126095	XRT/PC	2013-10-10 03:59:21	2013-10-10 04:11:53	737
00032126096	XRT/PC	2013-10-14 21:35:58	2013-10-14 21:49:55	815
00032126097	XRT/PC	2013-10-17 03:57:58	2013-10-17 04:12:56	875
00032126098	XRT/PC	2013-10-21 05:42:54	2013-10-21 06:04:56	1319
00032126099	XRT/PC	2013-10-24 05:41:12	2013-10-24 05:57:55	1003

**Table 3.** Observation log for IGR J16465–4507 (J16465).

Sequence	Instrument/Mode	Start time (UT) (yyyy-mm-dd hh:mm:ss)	End time (UT) (yyyy-mm-dd hh:mm:ss)	Net Exposure (s)
00032617001	XRT/PC	2013-01-20 04:09:45	2013-01-20 04:25:56	935
00032617002	XRT/PC	2013-01-23 04:20:53	2013-01-23 04:36:55	938
00032617003	XRT/PC	2013-01-27 01:20:53	2013-01-27 01:35:55	895
00032617004	XRT/PC	2013-01-30 22:34:44	2013-01-30 22:50:45	948
00032617005	XRT/PC	2013-02-03 19:12:14	2013-02-03 19:29:54	1043
00032617006	XRT/PC	2013-02-06 17:57:37	2013-02-06 18:15:55	1073
00032617007	XRT/PC	2013-02-10 19:48:15	2013-02-10 20:06:53	1098
00032617008	XRT/PC	2013-02-13 00:31:56	2013-02-13 00:47:53	938
00032617009	XRT/PC	2013-02-17 13:22:56	2013-02-17 13:38:53	953
00032617010	XRT/PC	2013-02-20 21:39:44	2013-02-20 21:57:55	1083
00032617011	XRT/PC	2013-02-24 11:58:31	2013-02-24 12:14:54	978
00032617012	XRT/PC	2013-02-27 23:19:43	2013-02-27 23:35:54	950
00032617013	XRT/PC	2013-03-03 20:14:01	2013-03-03 20:29:54	943
00032617014	XRT/PC	2013-03-06 20:31:45	2013-03-06 20:47:55	955
00032617015	XRT/PC	2013-03-10 09:35:53	2013-03-10 09:52:56	1013
00032617016	XRT/PC	2013-03-13 00:03:17	2013-03-13 00:17:56	820
00032617017	XRT/PC	2013-03-17 00:25:24	2013-03-17 00:41:47	983
00032617018	XRT/PC	2013-03-20 22:42:49	2013-03-20 22:59:55	1008
00032617019	XRT/PC	2013-03-24 13:23:47	2013-03-24 13:39:55	958
00032617020	XRT/PC	2013-03-27 02:24:54	2013-03-27 02:41:54	1010
00032617021	XRT/PC	2013-03-31 11:52:15	2013-03-31 12:08:55	993
00032617022	XRT/PC	2013-04-03 02:37:49	2013-04-03 02:53:54	958
00032617023	XRT/PC	2013-04-07 18:38:59	2013-04-07 18:54:55	943
00032617024	XRT/PC	2013-04-10 15:25:32	2013-04-10 15:41:55	960
00032617026	XRT/PC	2013-04-17 01:32:52	2013-04-17 01:48:55	955
00032617028	XRT/PC	2013-04-24 19:08:05	2013-04-24 19:28:54	1249
00032617029	XRT/PC	2013-04-28 09:53:42	2013-04-28 10:12:55	1153
00032617030	XRT/PC	2013-05-01 14:44:28	2013-05-01 14:59:56	908
00032617031	XRT/PC	2013-05-05 00:32:17	2013-05-05 00:53:54	1291
00032617032	XRT/PC	2013-05-08 05:20:35	2013-05-08 05:36:55	960
00032617033	XRT/PC	2013-05-12 21:55:42	2013-05-12 23:41:56	945
00032617034	XRT/PC	2013-05-15 21:36:49	2013-05-15 21:42:53	364
00032617035	XRT/PC	2013-05-19 01:12:11	2013-05-19 01:18:05	351
00032617036	XRT/PC	2013-05-22 09:07:41	2013-05-22 09:23:54	953
00032617037	XRT/PC	2013-05-26 09:16:54	2013-05-26 09:33:54	1010
00032617038	XRT/PC	2013-05-29 09:22:51	2013-05-29 09:40:55	1063
00032617039	XRT/PC	2013-06-02 09:31:33	2013-06-02 09:47:53	978
00032617040	XRT/PC	2013-06-05 19:22:49	2013-06-05 19:38:55	958
00032617041	XRT/PC	2013-06-09 09:56:31	2013-06-09 10:02:55	379
00032617042	XRT/PC	2013-06-12 16:21:26	2013-06-12 16:36:54	920
00032617043	XRT/PC	2013-06-16 03:38:35	2013-06-16 03:54:56	958
00032617045	XRT/PC	2013-06-23 02:03:29	2013-06-23 02:21:55	1096
00032617046	XRT/PC	2013-06-26 20:03:08	2013-06-26 20:18:54	943
00032617047	XRT/PC	2013-06-30 00:48:38	2013-06-30 01:04:53	958
00032617048	XRT/PC	2013-07-03 23:15:52	2013-07-03 23:33:55	1063
00032617049	XRT/PC	2013-07-07 18:33:51	2013-07-07 18:50:54	1000
00032617050	XRT/PC	2013-07-10 01:06:00	2013-07-10 06:02:56	870
00032617051	XRT/PC	2013-07-14 06:14:33	2013-07-14 11:19:54	903
00032617052	XRT/PC	2013-07-17 19:11:31	2013-07-17 19:28:54	1038
00032617053	XRT/PC	2013-07-21 14:13:37	2013-07-21 14:29:55	973
00032617054	XRT/PC	2013-07-24 06:24:07	2013-07-24 06:40:55	983
00032617056	XRT/PC	2013-07-31 11:30:13	2013-07-31 11:47:53	1053
00032617057	XRT/PC	2013-08-04 21:16:14	2013-08-04 22:36:54	1076
00032617058	XRT/PC	2013-08-07 06:51:42	2013-08-07 07:09:55	1091
00032617059	XRT/PC	2013-08-11 02:10:07	2013-08-11 02:26:55	988
00032617060	XRT/PC	2013-08-14 21:16:47	2013-08-14 21:31:55	885
00032617061	XRT/PC	2013-08-18 15:03:58	2013-08-18 15:21:54	1058
00032617062	XRT/PC	2013-08-21 03:58:44	2013-08-21 04:15:55	1020
00032617063	XRT/PC	2013-08-25 04:05:54	2013-08-25 05:52:54	890
00032617064	XRT/PC	2013-08-28 12:22:54	2013-08-28 18:51:56	820
00032617065	XRT/PC	2013-09-01 17:03:18	2013-09-01 17:20:56	1046

**Table 4.** Observation log for outburst data.

Source	Nickname	Sequence	Mode	Start time (UT) (yyyy-mm-dd hh:mm:ss)	End time (UT) (yyyy-mm-dd hh:mm:ss)	Net Exposure (s)
IGR J08408–4503	J08408	00559642000	XRT/WT	2013-07-02 08:13:08	2013-07-02 11:30:45	478
		00559642000	XRT/PC	2013-07-02 08:20:08	2013-07-02 11:49:07	4298
		00037881097	XRT/PC	2013-07-03 11:40:45	2013-07-03 11:57:20	975
		00037881098	XRT/PC	2013-07-04 06:35:35	2013-07-04 06:52:11	978
		00037881100	XRT/PC	2013-07-05 01:56:49	2013-07-05 02:14:55	1071
		00037881101	XRT/PC	2013-07-06 17:56:49	2013-07-06 19:39:55	1043
		00037881102	XRT/PC	2013-07-07 00:25:08	2013-07-07 00:41:56	995
IGR J16328–4726	J16328	00354542000	XRT/PC	2009-06-10 08:01:15	2009-06-10 13:00:51	8181
		00354542001	XRT/PC	2009-06-11 15:47:45	2009-06-11 16:04:18	993
		00354542002	XRT/PC	2009-06-12 15:50:48	2009-06-12 16:07:21	985
		00354542003	XRT/PC	2009-06-13 15:56:57	2009-06-13 16:13:30	975
		00354542004	XRT/PC	2009-06-14 00:13:26	2009-06-15 21:11:56	2827
AX J1841.0–0536	J1841	00524364000	XRT/WT	2012-06-14 19:18:55	2012-06-14 20:22:09	257
		00524364000	XRT/PC	2012-06-14 20:22:10	2012-06-14 20:57:44	2111
		00030988115	XRT/PC	2012-06-15 10:40:44	2012-06-15 12:52:45	700
		00030988117	XRT/PC	2012-06-17 11:17:45	2012-06-17 12:58:56	1018
		00030988118	XRT/PC	2012-06-18 15:57:33	2012-06-18 16:06:57	554
		00030988119	XRT/PC	2012-06-16 16:03:51	2012-06-16 16:15:58	705
		00030988120	XRT/PC	2012-06-19 03:32:33	2012-06-19 19:36:56	1246